Scholarly Paper

Ensuring That Safety Glass Is Safe

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Abstract: In Australia, the building code prescribes where glass in buildings must adopt certified safety glass. However, this standard still permits the certification and installation of toughened glass with a residual surface stress that is insufficient to ensure fragmentation in a safe manner. Until the standard is amended to assure safe fragmentation, other precautions need to be taken to ensure that glass installed in buildings is not potentially lethal. This paper discusses safety glass testing, explaining why the current testing procedure does not assure safe fragmentation, and, in the absence of adequate statutory-backed guidance, how building surveyors should navigate the compliance pathway for toughened safety glass. **DOI: 10.1061/(ASCE)LA.1943-4170.0000576.** *© 2022 American Society of Civil Engineers.*

Introduction

Sheet glass is supplied in bulk in an annealed state, with no residual stress from the manufacturing process. This is so it can be cut, drilled, edged, and otherwise worked. In the event of any breakage such as human impact, annealed glass breaks into large shards that have been known to cause serious injury and death. The first reported fatality occurred in 1875 when a man walked through a sheet of plate glass mistaken for a doorway (Hashemi and Subhedar 1986). During the 1960s and 1970s, healthcare professionals became concerned, leading to a large study in the United States, and subsequent federal legislation was enacted requiring the use of safety glass in 1977 (Maitra and Han 1989). As a result, when glass was used in buildings at locations where impact was likely, safety glass was to be specified and used.

In Australia, official standards for the installation of glass in buildings and its safety specifications for human impact were drafted in in the late 1970s. These standards were regarded as guidance documents, until the Building Code of Australia (BCA) [and subsequently the National Construction Code (NCC)] was first published in 1988 and referenced the glass safety standards and then, and only then, made the requirements mandatory (ABCB 1988). Prior to this, each state government had its own requirements. For example, in New South Wales, Ordinance 70 prescribed the need for safety glass in doors and sidelights.

Compliance with the NCC is achieved by complying with the performance requirements. In terms of glass safety, this is found under BP1.3, "Glass Installations At Risk of Human Impact":

Glass installations that are at risk of being subjected to human impact must have glazing that (ABCB 2019a)

1. if broken on impact, will break in a way that is not likely to cause injury to people;
2. resists a reasonably foreseeable human impact without breaking; and
3. is protected or marked in a way that will reduce the likelihood of human impact.

This requirement is deemed to have been satisfied when the Australian standard (Standards Australia 2006a), AS 1288:2006, has been complied with [NCC Volume One B1.4(h)(ii)][1]. This standard is considered a primary reference because the BCA directly references it. It in turn references AS/NZS 2208:1996 (a secondary reference) around prescribed testing for safety glazing materials (Standards Australia 1996). Both primary and secondary references are to be complied with in the context in which the documents have been quoted (ABCB 2019b).

Safety glass is classified as such by virtue of the fact that when it fractures, it either breaks into small, relatively harmless fragments (toughened safety glass), or remains substantially adhered to an interlayer that does not break but tears on impact (laminated glass), thereby "minimizing cutting and piercing injuries" (AS/NZS 2208:1996). By mandating the use of safety glass in place of annealed glass in locations where human impact is likely, severe injuries were reportedly reduced in Australia (Maitra and Han 1989).

In this paper the discussion is limited to toughened safety glass, also called tempered glass, as prescribed in the standard AS/NZS 2208:1996 (Standards Australia 1996). The breakage characteristics of toughened glass are discussed and explained with reference to its installation in buildings. This paper is written particularly for building surveyors in Australia (also called building certifiers in some states) who have a statutory responsibility to prevent the use of materials in buildings that are not fit for purpose.

Context

In the Australian state of Victoria, injury statistics are compiled by the Victorian Injury Surveillance and Applied Research System (VISAR) [previously Victorian Injury Surveillance System (VISS)]. VISS first wrote an account on domestic architectural glass injuries in 1990, reporting 178 cases of laceration injuries in children under 15 years in 1990. At that point, a particular interest in the issue of architectural glass injuries was flagged by VISS because the Australian standard AS 1288 on glass in buildings had recently been updated in 1989 (Standards Australia 1989), and Victoria's building code still referenced the 1979 standard (Standards Australia 1979) instead of the latest version (VISS 1991).

Since the 1970s, the glass standards (AS 1288 and AS/NZS 2208) have been published with special consideration for safety under human impact. The introduction to the standard requires that, when broken, "the likelihood of cutting and piercing injuries will be minimized" (AS 1288:1973, Standards Australia 1973). Other than minor word changes, these criteria for human impact safety

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Table 1. Hospital-treated injuries related to glass windows, doors, and shower screens, Victoria 2015/16 to 2020/21 (6 years). Injuries by age group

Age (years)	Frequency	Percentage
0 – 4	320	10.9
5 – 9	350	11.9
10 – 14	299	10.1
15 – 19	300	10.2
20 – 24	323	11.0
25 – 29	298	10.1
30 – 34	235	8.0
35 – 39	181	6.1
40 – 44	135	4.6
45 – 49	115	3.9
50 – 54	81	2.7
55 – 59	59	2.0
60 – 64	65	2.2
65 – 69	50	1.7
70 – 74	36	1.2
75+	100	3.4
Total	2,947	100.0

Source: Data from VISU, Monash University (2022).

have been repeated in subsequent updates (AS 1288:1989, AS 1288:1994, AS 1288:2006, AS 1288:2021).

When compared to a current data set, there has been little difference in the overall incidence of glass-related injuries in children over the past three decades. Currently an annual average of 162 children (Table 1) under 15 years present to emergency departments for architectural glass-related injuries. These are injuries related to windows, glass doors, and shower screens.

In 2002, VISS published a newsletter focused on cutting and piercing injury in the home. Glass was found to be the leading cause of unintentional cutting and piercing home injury accounting for 27% of admissions and 30% of emergency department presentations. The data set did not always record details of the glass items involved. Where case narratives were recorded, fixed architectural glass (predominantly window and door glass) was involved in more than half of all glass-related injuries in both adults and children. The most common scenario for children was falling through or hitting against a window; and for adults, punching window glass in anger or frustration, falling through window, or glass breakage during repairs (VISS 2002).

In the most current data set, over the period July 2015–June 2021, there were a total of 2,947 emergency department presentations from architectural glass-related injuries (Table 2). The most common injuries were open wounds (65.4%), the most common cause was cutting or piercing (43.5%), and the most common location where injury occurred was the home (72.9%). About one in four presentations were serious, i.e., requiring hospitalization for further treatment.

The persistent occurrence of cutting or piercing injuries resulting in open wounds should be of concern. These injuries were the ones for which safety glazing criteria were explicitly developed, defined as follows (Standards Australia 1996):

Safety glazing materials—materials constructed, treated, or permanently combined with other materials as to reduce the likelihood of cutting and piercing injuries resulting from human impact with them. All safety glazing materials are classified as either Grade A or Grade B according to the performance requirements in the section "Test Requirements."

The building surveyor, when thus confronted, needs to reevaluate if glass certification is all that is required, or if there should be further evidence to assure the fitness for purpose of safety glazing materials.

Table 2. Hospital-treated injuries related to glass windows, doors, and shower screens, Victoria 2015/16 to 2020/21 (6 years). Injuries by type

Category	Frequency	Percentage
Main injury type		
Open wound	1,928	65.4
Superficial injury	385	13.1
Other and unspecified injury	269	9.1
Fracture	100	3.4
Injury to muscle and tendon	67	2.3
Dislocation, sprain, strain	54	1.8
Foreign body	53	1.8
Intracranial injury	42	1.4
Crushing injury	30	1.0
Eye injury—excluding foreign body	9	0.3
Injury to nerves and spinal cord	5	0.2
Injury to blood vessels	5	0.2
Body region of injury		
Wrist and hand	966	32.8
Head	557	18.9
Elbow and forearm	477	16.2
Ankle and foot	249	8.4
Knee and lower leg	203	6.9
Multiple body regions	146	5.0
Shoulder and upper arm	132	4.5
Abdomen, lower back, lumbar spine, and pelvis	48	1.6
Other specified/code not required	47	1.6
Hip and thigh	44	1.5
Unspecified body region	42	1.4
Thorax	29	1.0
Neck	7	0.2
Main cause of injury		
Cutting/piercing	1,282	43.5
Hit/struck/crush	871	29.6
Fall	494	16.8
Other specified	206	7.0
Unspecified	94	3.2
Place of injury		
Home	2,149	72.9
Unspecified places	347	11.8
Other specified places	278	9.4
Trade and service area	76	2.6
School, public buildings	74	2.5
Residential institution	18	0.6
Industrial and construction area	5	0.2
Departure status		
Presentations	2,219	75.3
Admissions/transfers	728	24.7

Source: Data from VISU, Monash University (2022).

Primer on Toughened Glass

In the toughening process, glass is heated to a temperature of about 650°C. It is then rapidly quenched by jets of compressed air so that the surface layers are locked into position without any further contraction, while the internal part of the panel remains in an expanded state. When the internal part subsequently cools from further quenching, it also contracts and in so doing it permanently prestresses the two external surfaces in compression and balances this compressive stress with tension in the internal part. It is this residual tensile stress that causes the entire pane of glass to break completely into fragments once breakage has been initiated. The breakage characteristics will be determined by the level of stress (compressive on the surfaces and corresponding internal tensile in the center) developed by the processing conditions.

As the degree of toughening increases (i.e., the level of compressive stress on the surface), the size of particles generated when the glass is fractured reduces.

Any degree of toughening will improve glass strength; however, only beyond a surface compressive stress of about 50 MPa does the particle size start reducing. Heat-strengthened glass (which is glass processed in a similar fashion but not to a high degree of toughening) is "measurably stronger than annealed glass but breaks into fragments not unlike those of annealed glass" (Gardon 1980). It is for this reason that heat-strengthened glass cannot be used in applications where human impact safety is a concern, for which toughened safety glass will be required so that particle size is acceptable. The criteria and distinction between the two glass types are defined in the standard as follows (Standards Australia 1996):

Toughened glass—Glass which has been subjected to a special heat treatment, so that the residual surface compression stresses lies between 24 and 45 MPa.

Toughened safety glass—A glass which has been converted to a safety glass by subjection to a process of prestressing so that, if fractured, the entire piece disintegrates into small, relatively harmless particles. The residual surface compression is a minimum of 69 MPa.

We assert that 69 MPa is profoundly inadequate to achieve safe fragmentation of toughened glass of any thickness because at this compressive stress the breakage pattern is not compliant with the definition for safety glass.

Many toughening facilities in Australia already manufacture to a surface compression of 90 MPa for 6-mm-thick glass (Jacob et al. 2009)[2]. This is also inadequate to assure safe fracture in the event of human impact.

To achieve a high degree of toughening, and thus a high degree of fragmentation, the following conditions are requisite: heating to the right temperature range and a rapid rate of cooling (Gardon 1980). More cooling energy is demanded to toughen thin glass, by higher quenching rates, compared to thicker ones (Mognato et al. 2011).

For cracks to successfully fragment the glass, "it was essential that the glasses had an adequate depth of the compressive layer (approx. 20% of the cross section) as well as a high compressive stress. Here, the depth of the compressive layer and the fragmentation behavior were most likely dependent on the glass thickness when the glass thickness was thinner than 4 mm" (Lee et al. 2012).

In Australia, Grade A safety glass is generally to be specified where human impact is anticipated. Both laminated safety glass and toughened safety glass can meet the criteria of Grade A. Between the two, toughened safety glass is considered to be the cheaper alternative (Build 2022).

In a push to minimize construction cost, a risk emerges where glass could be insufficiently toughened for safe fragmentation under human impact. It is thus important, especially with toughened safety glass on the thin side—that is, of thickness 4–6 mm (Jacob et al. 2009)—that building surveyors be concerned whether toughened glass will indeed break on human impact into "relatively harmless pieces" as required by the building code, the standard, and as anticipated by regulators and consumers.

Safety Glass Testing

Grade A safety glazing can be determined by two test methods: a pendulum impact test (prescribed), or a fragmentation test (an alternative deemed to comply method).

The pendulum impact test (AS/NZS 2208:1996, Appendixes B and D) involves impacting the geometric center of a glass pane (typically restrained within a frame) specifically manufactured for

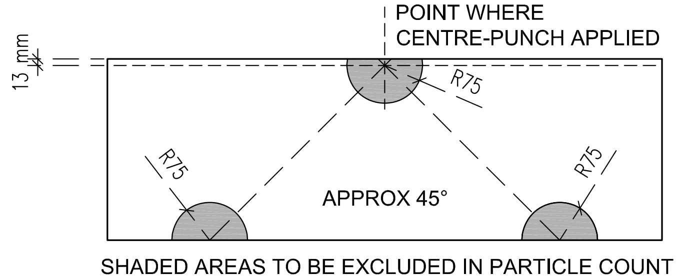

Fig. 1. Location at which glass breakage is initiated, and areas to be excluded in particle count determination, similar to EN 12150-1. (Adapted from AS/NZS 2208, Appendix E.)

the test of size 1,900 × 860 mm with a punching bag containing 46 kg of lead shot from progressive drop heights (300–1,500 mm) to simulate the kinetic energy from a running person impacting the glass first by the hands, then head and then knees. To pass the test, at least four specimens are required, all of which should meet one of the following criteria:

1. Breaks without allowing a 76-mm sphere to pass through freely; additionally, the total fragments and largest single fragment that detach up to 3 min after impact have a specified limited mass; or
2. Has broken and disintegrated but the 10 largest fragments selected 3 min after impact have a limited aggregate mass; or
3. Post-breakage the perimeter is not sharp or has limited pointed protrusions; or
4. Remains unbroken by the impact at all drop height up to 1,500 mm, whereafter breakage is initiated using a center punch. It passes if it disintegrates into small fragments of a specified limited mass, or cracks yet is held together in a safe manner. It fails if the broken large pieces can be pushed out of the frame.

The alternative, the fragmentation test, is used universally by manufacturers of toughened glass certified to AS/NZS 2208:1996. This is carried out on the floor or a flat wooden platform with the specimen broken by a center punch applied 13 mm inboard from the midpoint of the longest edge of the specimen (Fig. 1).

Within 5 min of breakage, the particle count is taken within an area 50 × 50 mm comprising the coarsest area outside the circular areas of Fig. 1. AS/NZS 2208:1996 stipulates how a particle is defined and how the counting is undertaken.

The specimen dimensions are not specified in the fragmentation test of AS/NZS 2208:1996 (Appendix E). As a result, the excluded areas in the test sample can be significant with a specimen of small dimensions, leaving a very limited region to pick the coarsest area of fragmentation.

Comparatively, in other standards such as BS EN 12150-1:2015, the specimen dimensions for a fragmentation test are stipulated as 1,100 × 360 mm (British Standards Institution 2015).

The fragmentation test represents a test method that is both cheaper and faster to undertake compared to the pendulum impact test. However, whereas the impact test has performance criteria specified that have been "directly related to the reduction of cutting and piercing injuries to persons who impact the glazing used in buildings" (Standards Australia 1996), the fragmentation test has a tenuous link with safety under human impact.

Limitations with Fragmentation Testing

The fragmentation test is a method to verify that a batch of product from the glass processing plant is appropriate for the given thickness and batch (Zaccaria and Overend 2020). It does not demonstrate or

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evince how glass will break under human impact. Instead, it is premised on the association between fragment count and residual surface stress (Ruusunen and Aronen 2019; Kraus et al. 2019), assuming that with sufficient residual stress the toughened glass can be expected to break in a relatively harmless manner.

With fragmentation testing there are a number of caveats, which will be elaborated:

1. The fragmentation count is only an approximation of its residual surface stress.
2. The fragmentation count is influenced by the location of the fracture initiation.
3. The boundary conditions (such as the presence of frames) can lead to undesirable fragmentation even when the surface compression of the glass is high.

The correlation between fragment count and residual surface stress is only "a rough measure" of the degree of toughening (Gardon 1980). There is limited information regarding testing to determine a relationship between residual surface compressive stress and fragmentation of glass (Jacob et al. 2009). Among some US glass experts, "there is speculation that fragmentation testing may have been performed by certain glass fabricators prior to the 1997 ASTM C1048 revision; however, the results of such testing were never publicly released" (Schmidt 2010). Some researchers even consider the fragmentation test to be a "dubious," "inaccurate," and "unsafe" basis for ascertaining its structural properties (Nielsen 2009).

For the building safety glazing standard, the site for initiating fragmentation has remained unchanged since it was first published in 1978 (Standards Australia 1978) and updated in 1996 (Standards Australia 1996), specified at 13 mm inboard from the midpoint of the longest edge.

Comparatively, AS 2080:2019 (Standards Australia 2019) has been updated from the same initial specification, then subsequently to a central position as known to be appropriate and in accordance with the international standard UN/ECE R43 (Publications Office of the European Union 2014), as follows:

1. "broken by means of a center punch, the point of impact being 13 mm inboard from, and at the midpoint of, the longest straight or curved daylight opening of the glass" [AS/NZS 2080:1995 (Standards Australia 1995)];
2. "30 mm inboard from and at the midpoint of the longest edge of the specimen" [AS/NZS 2080:2006 (Standards Australia 2006b)]; and
3. "broken with a punch applied at the geometric center" (AS 2080:2019).

The significance of the break initiation is this: a high fragmentation count tends to be more likely when breaking glass near its edge, as seen from the following quote:

> It is a very known behavior that the glass fragmentation depends on where you break the glass. If you break the glass in the center, you can get long shards, but if you break it on the edges, then usually the fragments are smaller. And that's because you have different boundary conditions depending on whether you break the glass in the center or on the edge. If you want to get smaller fragments even if you break the glass in the center, you can increase the stress level by tempering the glass at a higher temperature and with the higher cooling power. Then, the size of the fragments will get smaller. (Aronen 2020)

The working group for AS/NZS 2208 undertook a series of tests using toughened glass from Australian manufacturers and found that edge fragmentation did not reveal dangerous particles, but when toughened glass was broken in the center of the pane, long particles, or splines, developed well in excess of 100-mm length (Jacob et al. 2009). There are no limitations for maximum spline length in AS/NZS 2208. As a reference, BS EN 12150-1:2015 limits the longest particle to not exceed 100 mm in order to be classified as toughened safety glass.

Besides the break initiation location, the working group also found that the length of the longest particle was clearly influenced by the specimen size: longer splines developed when larger panels were broken in the center. In the case of 4-mm-thick Grade A safety glass, a pane area of up to 2.2 m^2 is permissible in building installation under AS 1288:2021 (Standards Australia 2021); however, the size of an acceptable test specimen can be much smaller, even though it will fragment with very different characteristics.

In a series of tests by the University of Sydney to compare Australian testing standards against in-service failure of toughened glass (Aronen and Kocer 2015), the formation of long shards was found to occur in test specimens 350×350 mm with the following cofactors:

1. Initiation of breakage at the center of glass;
2. Overall bending in the pane; and
3. Constraints at the glass edge (for example, the presence of framing and sash).

It would appear that the pendulum impact test, as opposed to the fragmentation test described in AS/NZS 2208:1996, more closely reflects these in-service factors by the use of the weighted bag positioned at the center of a framed test specimen, producing spherical bending in the glass pane on impact. The impact test indeed reveals the potential for Grade A toughened safety glass certified to AS/NZS 2208:1996 to form dangerous splines.

The acceptance criteria of the impact test in AS/NZS 2208:1996, where the mass of the 10 largest loose fragments is no more than the mass equivalent of 6,500 mm^2 of the original test piece, could allow a specimen to pass the test that nevertheless produced a small number of long particles with the potential to cause injury. Hence, the "criteria used to evaluate the broken glass sample [by mass of particles] have been found to be irrelevant and incorrect" (Jacob et al. 2009).

We present tests documented by Kidsafe Australia (Kidsafe Child Accident Prevention Foundation of Australia 2017). Three identical specimens of 4-mm-thick toughened safety glass were tested. Each piece of the glass tested was permanently marked with the "Certified Product 5 ticks" logo, as Grade A safety glass certified to AS/NZS 2208.

Photographs of the edge-initiated breakage (Fig. 2) show an adequate amount of fragmentation to likely meet the requirements for Grade A safety glazing material according to the current standard.

When the breakage point was relocated to the center of the next sample, the glass was observed to break into large pieces (many with sharp points), which were manifestly dangerous (Fig. 3).

In a pendulum impact test (Fig. 4) with another similar sample, long dangerous splines developed. As mentioned previously, these splines could still pass the (mass) acceptance criteria for the impact test as set out in AS/NZS 2208:1996.

Discussion: Safety of Architectural Glass

The matter of glazing safety is not only a matter of concern for Australia, but also for other countries where standards are underpinned by Australian standards. For instance, the Singapore standard (SPRING Singapore 2001) SS 341:2001 "is largely based on Australian Standards AS/NZS 2208:1996—*Safety glazing materials in buildings*" (Singapore Productivity and Standards Board 2001).

In Singapore, a fatal bathroom injury involved a male slipping and falling into a shower screen that fragmented and pierced his

(a) (b)

Fig. 2. (a) Test 1, 4-mm glass is broken 13 mm from the edge according to the test method in AS/NZS 2208; and (b) same image with the fragmentation count area enlarged. (Reproduced from Kidsafe 2017, with permission.)

(a) (b)

Fig. 3. (a) Test 2, 4-mm glass is broken using the fragmentation test, but at the center of the glass—this test is not currently specified in the Australian standard AS/NZS 2208; and (b) clumping of particles to form larger pieces observed. (Reproduced from Kidsafe 2017, with permission.)

neck, causing severe and uncontrolled bleeding (Baker 2015; Heng 2015; Law 2015).

In 2019, Australian competition regulator and national consumer law champion the Australian Competition and Consumer Commission (ACCC) recalled 4-mm toughened safety glass manufactured by Landson Glass Pty Ltd. on grounds that "if the glass breaks, it may break into fragments/particles and pose a risk of injury to anyone that comes into contact with it" (ACCC 2019). Evidently, it is not the attainment of certification by test, but actual breakage character that is of paramount importance.

How should a building surveyor navigate the issue of toughened safety glass when mere certification does not assure that the glass will achieve its safety definition of breaking into "small relatively harmless particles"? (AS/NZS 2208:1996) What if the deemed to satisfy certification criteria for toughened safety glass (AS/NZS 2208:1996) does not accord with the safety performance requirements of BP1.3 of the BCA? Safety should first be clearly defined, and then it would be obvious if the fragmentation test is an appropriate safety certification.

In Australia's National Injury Prevention and Safety Promotion Plan: 2004–2014 (NPHP 2005), safety has been defined as "being at little or no risk of injury. . . . injury usually means physical harm to a person's body." Broken annealed glass can cause "lacerations, cuts, and puncture wounds which may result in severed arteries or tendons, amputations, eye injuries, or exposure to disease" (OSHA 2015). Because toughened glass of the thinner variety and inadequate degree of toughening breaks with similar characteristics to annealed glass, it cannot be considered to be safe.

In ballistics research it was found that the energy densities required for 50% risk of penetration at the front or back of the rib were 24 and 53 J/cm^2, respectively (Bir et al. 2005). In comparison, the impact of a person falling in a confined space, such as in a shower, is taken to be 90 J (AS/NZS 2208:1996), more than sufficient to result in serious penetration injuries when a glass spline is held in place against a falling body, with ample energy density to puncture the body.

In an assessment of the location of vital organs, so as to ascertain the depth at which a stab could be considered fatal to an adult, the spleen was found to be the shallowest organ at 9 mm deep, and the right kidney the deepest organ at 56 mm deep (Bleetman and Dyer 2000). Many of the particles formed as a result of breakage at the center (be it fragmentation or impact test) would be long enough to cause potentially fatal injuries.

For toughened glass to break safely, there should be a degree of toughening that ensures adequate fragmentation. This should happen regardless of where the breakage was initiated and whether or not the glass was under strain.

(a) (b)

Fig. 4. (a) Test 3, pendulum impact test, specified in the Australian standards as an option, but generally not used to test and certify toughened safety glass; and (b) close-up view of long dangerous shards generated. (Reproduced from Kidsafe 2017, with permission.)

The surface compressive stress to be confident of safe fracture should be at least:

- 105 MPa for 6-mm glass;
- 115 MPa for 5-mm glass; and
- 125 MPa for 4-mm glass.

These values were extracted from many tests carried out over the last 15 years, including those by the AS/NZS 2208 working group of Committee BD/7 of Standards Australia. Unfortunately, Committee BD/7 was not willing to adopt into AS/NZS 2208 the test protocol (fragmentation at the glass panel center) or the compressive stress criteria established by the systematic testing carried out under the auspices of the working group (composed of any member of BD/7 willing to attend).

The first listed objective of the Building Act 1993 is "to protect the safety and health of people who use buildings and places of public entertainment" [s.4(1)(a)]. Regulation-making powers concerning the safety of buildings [Schedule 1(34)] are given to the Governor in Council (s.7) or local council (s.8). However, in day-to-day discretionary decisions it would be the municipal building surveyor or relevant private building surveyor who may issue a building notice, and thereafter a building order, if of the opinion that the building was a danger to safety (s.106, s.111).

The relevant building surveyor (RBS) in turn relies on compliance with the BCA and referenced documents such as the Australian standards to ensure minimum safety requirements are met. However, during the Senate inquiry into nonconforming building products (Economics References Committee 2016), Adam Stingemore, representing Standards Australia, revealed the priorities of organizations such as Standards Australia and the Australian Building Codes Board:

> Standards Australia is policy-neutral. We have no technical agenda. Our process is one that provides a forum for industries, governments and community interests to do this for themselves. … Standards Australia develops voluntary technical documents … How those documents are used is a matter for industries and governments. … The Australian Building Codes Board maintains a protocol for the development of reference documents. There is an economic impact assessment that is undertaken in respect of the consideration of those documents, and governments make choices about whether the documents are accepted through that process on the basis of the preliminary impact assessment or the regulatory impact statement that would be provided.

Phil Jones, a representative from the Australian Glass and Glazing Association said:

> I do not think either [center or edge initiated fragmentation] faithfully represents or duplicates what happens in a real-world circumstance. It is simply accepted by the industry that if the current test is passed against the current criteria, that glass will be released into the community. … While BD/7 can in fact produce a standard and even have it certified as a standard, you have the Building Codes Board, which can tell you that it will not call up that standard if it does not like it. So the cost-benefit analysis that was being discussed previously is a requirement of the Building Codes Board. If you produce a standard that they are not prepared to accept, then the standard will be produced but it will not be called up in the Building Code of Australia. … the things that I would think Standards Australia are very wary of: what is the point in them having a glass standard that the Building Codes Board refuses to call up in the Building Code of Australia? I can assure you that that happens because, within the BD/7 room and discussion environment, I have been told that by the Building Codes Board representative.

One may argue that building surveyors are proscribed from exceeding the minimum standards that have been deemed to satisfy the performance requirements, citing the Building Act 1993 [s.24(2)]:

"the relevant building surveyor must not issue a building permit that imposes on the applicant lesser or greater standards or requirements than those prescribed by this Act or the building regulations, unless permitted to do so by this Act or the building regulations." Because the BCA is incorporated into the legislation by reference (Building Act 1993, s.9), it appears the RBS cannot require more than the BCA in their statutory role.

However, on closer inspection, we find that the legislation is not stating that compliance with the BCA automatically and completely satisfies the act and regulations [Building Act 1993, s.9(1)]:

> The building regulations may apply, adopt or incorporate, either wholly or in part and with or without any modification, any matter contained in the Building Code of Australia or any other document as in force or as issued or published at a particular time or as in force or as issued or published from time to time.

The BCA is not the whole embodiment, but a part of all that must be complied with. This flexibility to incorporate in whole or in part also means the legislation can require a standard higher than the BCA, and it indeed does. There is a requirement for fitness for purpose, seen in r.120 of Building Regulations 2018, where it is stated:

> Testing of Materials
> 1. The relevant building surveyor may require that the owner or builder carrying out building work for which a building permit has been issued arrange for the testing of any material used in the building work.
> 2. The relevant building surveyor may, as a result of tests carried out under subregulation.
> 3. Prohibit the use of any material that
>   - does not meet the requirements of these Regulations; or
>   - is found to be unsuitable or unfit for the purposes for which it is intended.

When it comes to fitness for purpose, the BCA not only makes no claim to that, it makes an explicit disclaimer under its copyright and license notice:

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The BCA sets the minimum required level for the safety, disclaims fitness for purposes, and accepts no liability for negligence. The building legislation, on the other hand, requires fitness for purpose as a minimum, and entrusts the building surveyor with that duty of care to the building owners and to the public.

The need for the building surveyor to exceed the minimum standards of the BCA has been elucidated previously in this journal, explained by a gap that exists between the minimum acceptable standards of the BCA as distinct, and in some situations insufficient, compared to being fit for purpose as required under the building legislation (Law 2021). We believe the misunderstanding of these distinctions has resulted in building surveyors being hesitant to exceed the BCA, and thus assuming a disproportionate risk exposure.

Because building surveying was privatized in Australia in the mid-1990s, the overwhelming majority of building surveying work is now undertaken by private building surveyors. In Victoria, 90% of permits are currently being issued by private building surveyors (Building Reform Expert Panel 2021). We are aware that it is an extremely challenging task for private building surveyors to be disquieted about public safety in the absence of reliable glass safety standards. The privatization of building surveying, while making the RBS the sole custodians of public safety under building legislation, has created a perennial dilemma for private building surveyors to set sufficiently high standards while making a sufficient income.

An earlier audit of building compliance in Victoria, still applicable today, found "building surveyors also advised that skills shortages and the day-to-day pressures of dealing with high workload demands has led them to seek practical, efficient approaches to assessment. This, however, neglects their underlying obligation to observe statutory requirements. It also points to a need for greater leadership from the commission to address the challenges raised by building surveyors and to authorize, where appropriate, any related departures in practice from mandatory requirements" (VAGO 2011).

In relation to glazing safety, the standard is technically defective in so far as it does not ensure glass performance in accordance with what it purports to ensure—the minimizing of cutting and piercing injuries. The standard, and by extension the BCA for accepting the standard, is also a deviation from the mandatory requirements to be fit for purpose. The RBS, if they are to ensure that building designs and specifications are fit for purpose and safe for use—and not merely compliant with the BCA—would require glazing suppliers to furnish sufficient documentation regarding the testing of toughened safety glass that demonstrated that safety glass was safe in the event of human impact.

Having reviewed the technical aspects of glass engineering and the legal obligations of building surveyors, the paper consolidates this knowledge in a review of the following relevant court case.

Case: *Giner v. Public Trustee and Anor* (1991)

In *Giner v. Public Trustee and Anor* (1991), the property owners were found guilty of breaching their duty of care to the occupier, who, in 1980, was an 11-year-old child that ran through a glass door and suffered deep transverse lacerations that almost severed her leg.

An architect giving evidence for the plaintiff said that the glass in the doors, if one were to assume the glass was annealed, was not in accordance with the standard AS 1288 requiring toughened or laminated glass. At the date when the doors were believed to be installed, this standard was nonexistent. At the date of the accident, this standard was not yet mandatory.

Counsel for the defendants objected to the architect's testimony on the basis that (1) there was no evidence that the glass was annealed, (2) a nonmandatory standard should not be admissible, and (3) a standard should be relevant at the date of building rather than the date of the accident.

Objection 1

The judge rejected the first objection on the basis that he had found the glass was annealed for the following reasons:

- The physician who attended to the plaintiff when she was first treated was of the opinion that the wound was more consistent with that from annealed glass than by toughened or laminated glass.
- The plaintiff's mother's description of the glass that remained in the door frame was consistent with the breakage characteristics of annealed glass.

- The testimony of the plaintiff's cousin who was playing with her when the accident occurred recalled that the broken glass under the plaintiff's knee was jagged and had sharp edges.
- The judge expressed, "I consider that nearly everybody would be familiar with the different appearance of these two types of glass when they break. Most people would be aware that ordinary glass when it breaks, will leave large sharp pieces capable of inflicting a serious cut; whereas anyone who has seen a car windscreen shatter, would be aware that the glass pieces are usually much smaller and blunter."

When the judge found the glass to be annealed glass, it was not based on prior glass certification or subsequent test reports. He ascertained that the observations from witnesses were credible because if safety glass had been used then it should have been observed by them to break like car windscreens. A glass pane that broke with the characteristics of annealed glass, resulting in hazards similar to annealed glass, will, for the purposes of safety, be considered to be annealed glass. Inadequate heating or low quenching rates have been known to cause large fragmentation pieces in tempered glass (LandGlass 2022). Thus, glass that has gone through the tempering process does not necessarily become tempered safety glass—the ultimate criterion was that the glass had to fragment into relatively harmless pieces when broken on human impact, similar to what could be observed in vehicular windscreen breakage.

Objection 2

The judge also rejected the second objection that the AS 1288 standard was inadmissible because it was not an officially mandated publication. He conceded that the standard had no legal force; nevertheless, citing *Chicco v. The Corporation of the City of Woodville* (1990), it was permissible for an expert on safety to "have recourse to such published standards, if he sees fit, as one of the sources from which he informs himself as to matters relating to the subject on which he is expert."

If the building owners owed a duty of care to their tenants to be experts in safety, by argument from the lesser to greater, it would be all the more reasonable to expect that a building surveyor should have recourse to the most up-to-date information, seeing they have statutory responsibility for prohibiting the use of materials in buildings that are either not fit for the purposes intended or which do not meet the regulations (Building Regulation 2018)—for which we find safety in buildings to be the first stated objective of the Building Act [s.4(1)(a)]. The BCA is not retrospective in its application, but the duty of care around matters of safety needs to be current for those offering expertise on safety. In this respect, although AS 1288 was not a mandatory standard at the point of the accident, it could be expected from building owners' owing a duty of care owed to tenants; so this paper and the referenced studies, though nonmandatory, can also be the basis for informing building surveyors why and how they should update their safety requirements.

Objection 3

The third objection that a standard was only relevant at the date of construction rather than the date of accident was also rejected. The judge deemed that the relevant question was "whether there had been a breach of duty of care at the time of the accident, not at some time earlier."

The relevant building surveyor for a project retains statutory authority for an unspecified duration after an occupancy certificate has been issued [Building Act 1993, s.107(2)], being continually engaged in what is effectively a locked-in statutory retainer (Cotton 2020). This includes statutory powers to issue building notices and building orders if of the opinion a building is a risk to the safety of any member of the public or user of the building [s.106(d)]. Consequently, there is an ongoing duty of care by the RBS to ensure the safety provisions of buildings are constantly updated in light of new information.

To summarize, there is ample reason for a building surveyor to voluntarily exceed the mandated minimum standards found in AS 1288 and AS/NZS 2208, especially where there is reason to believe these standards are inadequate for public safety. For the purposes of safety, it is a moot point whether the glass has been certified to be a safety glass or not. If on human impact it breaks like annealed glass and cuts like annealed glass, in court it will be considered to be as dangerous as annealed glass.

Recognizing that tempered glass certified to AS 1288 and AS/NZS 2208 can still break dangerously, it would be reasonable for a relevant building surveyor to require a residual surface stress higher than what is presently mandated, or alternatively to require fragmentation testing to the vehicular standard (initiated at the center, AS 2080:2019) instead of the building standard (initiated near the edge, AS/NZS 2208:1996).

Conclusion

Long splines result from human impact when glass is insufficiently toughened. This appears to be a particular problem for glass thickness up to 6 mm because thicker glass is easier to toughen.

For tempered glass, the BCA has a performance requirement that such glass when installed in a building if subjected to human impact must break in a way that is not likely to cause injury. This requirement is deemed to be satisfied through the fragmentation test. However, the fragmentation test in AS/NZS 2208:1996 (initiated at the panel edge), generates a higher fragmentation count compared to the test in AS 2080:2019 (initiated at the panel center) and does not assure safe breakage in the event of human impact. As a result, Grade A toughened safety glass certified to AS/NZS 2208:1996 could break with dangerous splines under human impact. Many random tests of commercially supplied certified glass have demonstrated that unsafe toughened glass is endemic in Australia.

The building surveyor is confronted with the incidence rate of architectural glass injuries: 2,947 cases in 6 years within the state of Victoria alone. Certified toughened safety glass in the thinner varieties could fragment in such a manner that will contribute to such injuries.

Building surveyors are entrusted with ongoing statutory responsibilities to ensure that the buildings they permit are safe for any user. Because there is a discrepancy between the acceptance criteria of safety glass in the BCA and its fitness for purpose in the Building Regulations 2018, building surveyors should insist that toughened safety glass (up to and including 6 mm in thickness) installed in buildings is toughened to the levels of compressive stress detailed in this paper and should request formal certification. Alternatively, they could accept toughened safety glass genuinely certified to the automotive glass standard, AS 2080:2019 .

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Building Regulations 2018, Victoria, https://www5.austlii.edu.au/au/legis/vic/num_reg/br2018n38o2018281/.

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Endnotes

[1]At the time of writing, the current version of the National Construction Code is NCC 2019, referencing AS 1288:2006. A preview of NCC 2022, which references the updated AS 1288:2021, has been released. These updates will make no difference to the thesis of this paper.

[2]The fact that Australian manufacturers are voluntarily exceeding the standard with residual surface compression of 90 MPa should be of particular concern to building surveyors and certifiers who accept imported glazing certified to the lower but compliant specification of 69 MPa to meet AS 2208:1996 definitions.

[3]The full disclaimer in the NCC reads, "The Australian Building Codes Board, the Commonwealth of Australia and States and Territories of Australia do not accept any liability, including liability for negligence, for any loss (howsoever caused), damage, injury, expense or cost incurred by any person as a result of accessing, using or relying upon this publication, to the maximum extent permitted by law. No representation or warranty is made or given as to the currency, accuracy, reliability, merchantability, fitness for any purpose or completeness of this publication or any information which may appear on any linked websites, or in other linked information sources, and all such representations and warranties are excluded to the extent permitted by law. This publication is not legal or professional advice. Persons rely upon this publication entirely at their own risk and must take responsibility for assessing the relevance and accuracy of the information in relation to their particular circumstances (ABCB 2019a)."

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