A REVIEW OF ISSUES
RELATING TO THE USE OF SACRIFICIAL 'ANTI-GRAFFITI FILMS'
FOR THE CONSIDERATION OF
PUBLIC TRANSPORT OPERATORS
AND REGULATORY BODIES

The Government is committed to new legislation that will hold senior officers of companies personally responsible for the "corporate negligence" of their organisations. There is an increased propensity for the population at large to seek remedy through litigation. In view of these two facts alone, engineering managers within transport operators are advised to carefully consider the safety implications arising from the use of on-glass films before authorising their use.

A mark scratched into the surface of glass by a vandal is called 'etched graffiti'. This type of vandalism is becoming an increasing problem and a rising expense for many public transport operators – bus, coach, light and heavy rail. Etched graffiti is the most difficult of all graffiti to deal with; it cannot be 'cleaned-off'. Glass has to be replaced. Sacrificial films have been offered to operators as a solution from organisations outside the industry. There are secondary benefits from the use of the films that may be of interest to operators who are not suffering etched graffiti. PSV Glass is aware that the use of any type of film on toughened transport glass dramatically affects its break performance. Films applied to the inside of vehicles raise significant safety-compromising issues.

In the absence of any known published guidance from advisory authorities, this document seeks to fully explain the issues for the benefit of operators and other interested parties.

This document provides:

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The Issues in Detail

1 ANTI-GRAFFITI FILMS ARE AMONGST A WHOLE RANGE OF SPECIALIST FILMS

There are many specialist on-glass films that have been developed by well known makers of industrial films, such as 3M and Avery Dennison. The films are generally polyesters with good optical properties that do not materially detract from the optical performance of the glass to which they are applied (beyond any intended tinting). They fall into a number of groups:

- Safety and security — At the instant glass breaks, minute glass shards (spall) are thrown off the surface of the glass at high velocity. Sometimes called 'anti-spall films' these films contain the shards and prevent personal injury - especially to eyes. The films are also designed to hold the glass intact and increase its resistance to penetration – at their performance extreme, the films have anti-ballistic properties.
- Thermal insulation — Reduce heat loss through glass as well as incoming heat transmission; also reduce glare. Primarily used in architectural applications.
- Fade reduction — Reduce ultra-violet transmissions with much less light reduction than solar films. Especially used to protect valuable objects – e.g. in museums and art galleries.
- Full solar protection — Reduce glare, heat and ultra violet transmissions through glass. The films give the benefits of reduced eye-strain, easier maintained interior temperatures, and avoidance of 'fading'.
- Tinting & obscuration — Tinted films achieve a colour effect without glass replacement. Obscuration films range from white opaque, to heavily tinted (sometimes seen as 'black' glass in private cars).

Without implying a technical challenge to film manufacturers, it is fair to say that whilst these various films may vary considerably in visual appearance, there is a great deal of overlap in terms of their transmission-effect performance. Films with enhanced physical properties fall within the safety and security group.

1.1 Glass protection films

These films are an adaptation of products from within the safety and security group.

- Glass protection films have long been used in architectural applications.
- Despite its hardness, glass is vulnerable to surface marking, particularly by the 'wrong' sort of hardened object. In many applications, glass is vulnerable to wear and accidental damage in normal service life (glass partitions/doors in high traffic areas, shop sales counters, etc).
- Obviously, unlike other surfaces, glass cannot be simply repainted or recovered. The only remedy is replacement. This is not always a practical solution, and can often be expensive.
- Enterprising businesses have previously found other market uses for these types of film:
  - Applied to the inside of car windows, the film prevented a broken glass from being pushed-in, thereby preventing theft of content, and hi-jacking. This application had a serious safety-compromising effect, and as a result, a number of US law suits followed. Such a use was evaluated in the UK about 8 years ago by a national auto-glazing company, and abandoned on the grounds of safety and limited application.

1.2 Anti-graffiti films

The anti-graffiti use is another technical and marketing adaptation for glass protection films.

- Obviously, films that are capable of offering a degree of protection against accidental damage are also a defence against deliberate damage, and the vandalism now called etched graffiti.
- Given the fact that they are developments of security films, anti-graffiti films are, in many respects, the technically most sophisticated on-glass films offered by film manufacturers.
- The films are thus offered as a 'solution' for the rapidly escalating problem of etched graffiti.
- Prima facie, the anti-graffiti application clearly offers significant attractions.

The proposition is simple - which is better?

Etched graffiti that can neither be concealed nor removed other than by replacing the glass; **OR** an undetectable film applied that protects the glass -

- that can be peeled off once it has been scratched;
- then replaced with a new film, conveniently cut to shape from rolls or sheets;
- that costs less than glass; that doesn't need specialist (and expensive) glazing labour;
- that can also be more practically used as evidence for a prosecution.
- **There is no doubt that anti-graffiti films are easier and cheaper to replace than glass.**

2 IS ONE FILM BETTER THAN ANOTHER?

- A comparison of anti-graffiti films' technical data sheets, does reveal differences.
- Whilst these high-level technical differences are measurable and do differentiate the products, there is a question as to whether the differences have any significance in practical anti-graffiti performance terms:
  - A multi-layer construction laminated into a single sheet might claim to offer special advantages from its constituent parts. The more layers, the more it might claim. The complexity of such structures can have a meaningful anti-spall effect, but it is questionable whether the lamination is, in reality, capable of achieving anything of significance against the physical nature of a determined vandal attack.
  - A 150micron film is twice as thick as a 75micron film, and might therefore be claimed to be twice as resistant. In practice, to achieve the desired effect, the vandal merely has to press a little harder.
  - A 'hard-coating' suggests a performance advantage, but since polyester films are much softer than glass (and given that vandals can scratch glass) does a hard-coated film have a meaningful advantage over a softer one?
- For the practical issues of application:
  - The thicker and/or more 'rigid' the film, the more easily it can be handled;
  - The greater the longevity of the adhesive's 'removability', the longer the film's workable life.

3 DO 'ANTI-GRAFFITI FILMS' REDUCE THE OCCURRENCE OF ETCHED GRAFFITI?

- The films do not actually prevent etching; they merely attempt to protect the glass from it.
- Those marketing the films suggest that their use will discourage etched graffiti.
- Others have suggested that the films will actually encourage it.
- Current UK use of the films is very limited; there is no empirical evidence one way or the other.
- There are two, contradictory, theories – the "discouragement" and the "encouragement".

3.1 The "**discouragement**" theory - films will dis-incentivise vandals

3.1.1 The loss of longevity

- Evidently, vandals are looking for gratification from the knowledge that their handiwork will have some longevity (for self-identity reassurance, or for maximising offence to others).
- Longevity is evidence that the graffiti is difficult (and expensive) to remove.
- It follows that if their vandalism is seen as being easily and inexpensively removed, it loses its purpose, and vandals will be discouraged from etching.

3.1.2 Graffiti encourages graffiti (a sociologically acknowledged fact)

- Films will facilitate easier removal, thereby removing the impetus for others to create more.

3.1.3 Will this theory have relevance for UK public transport?

- There IS very clear empirical evidence that these arguments have real validity. The experience of the New York Transit in reducing painted graffiti is clear testimony. BUT this experience was within a zero-tolerance environment famously championed by the City Mayor, and heavily supported by the NYPD and the city's courts.
- Whether that experience is capable of repetition in the UK given apparent police shortages and with, perhaps, a less fervent judiciary, is a matter of speculation.
- Moreover, these arguments seem to depend on some sort of logic in vandals' behavioural patterns – the need for longevity, the need for reassurance and/or offence, the desire to cause corporate expense, mimicry and so on.
- If, on the other hand, a UK vandal is acting out on an adhoc and/or whimsical basis, logically based defence systems might be of limited value.
- Nevertheless this general hypothesis/suggestion has common sense appeal, and must have some positive effect on the reduction of glass etching.
- There has been a small-scale film trial on London buses where this was the experience. However, it is entirely unknown whether the absence of etched graffiti was due to the film. It might, for example, have been the fact that particular vandal(s) had not travelled on the trial vehicles in the trial period, or that the trial vehicles had also been fitted with CCTV.

3.2 The "**encouragement**" theory – films will encourage/facilitate graffiti

3.2.1 Films are easier to permanently mark than glass.

- Films are "softer" than glass. A coin, for example, will permanently mark a film, but will have no effect on glass. Any potential vandal will be more likely "equipped" to mark a

film than they would have been to mark glass.

- Given that it's much easier to mark – the argument is that films will facilitate more etching than might otherwise have been possible.
- Moreover, the 'graffiti encourages graffiti' theory would then suggest that films could accelerate the rate at which graffiti is applied.

3.2.2 Films could introduce new, film-specific, types of vandalism:

(a) Scorching (and other fire damage)

- There are suggestions that films could be:
  - scorched with, say, a cigarette lighter, to create a new genre of marks.
  - peeled off and used to set a fire.
- There is no evidence of this anywhere, and PSVG trials indicate that this is unlikely to be a problem. Notwithstanding the fact that some products have fire resistant qualities, the glass itself acts as a heat sink, dissipating the heat away from the source, keeping the film below scorching temperature.
- It is extremely unlikely that a vandal will carry a sufficiently high-temperature heat source.
- If heat/fire were to be the chosen attack, there are easier softer targets (e.g. seats).

(b) Peeling and stencilling

- Given that the film is removable, vandals might just peel it off for an effect in itself.
- Vandals unaware of etching as an 'outlet', or unwilling or unequipped to etch, might get gratification from idly picking up a corner (or edge) of the film and peeling it back.
- It is possible to cut the film with a sharp blade. Lines cut into the film and then selectively peeled off can create shapes and words.

PSVG is not aware of any of this having happened (or not happening) in the US. Whilst these types of vandalism are possible, there is so little UK use, these suggestions should be regarded as mere speculation.

4 ARE THE FILMS NOTICEABLE ON THE GLASS?

Anti-graffiti films are intrinsically optically correct, and will not be noticed by regular passengers.

- It is a moot point as to whether or not films should be noticeable to vandals:
  - The **discouragement** theory suggests that it is better that vandals DO know the glass is protected – that is why they will be dis-incentivised.
  - The **encouragement** theory requires that the vandal should NOT know the film is present.
- In reality, both theories are likely to apply simultaneously depending on the individual vandal. An operator will have to take a view against the background of the etching problem they face. Either way, it becomes necessary to consider how noticeable films are once applied to glass.

4.1 Noticeablity BEFORE BEING MARKED

Films are noticeable due to their physical characteristics, and the skill with which they have been applied.

4.1.1 If the film has been WELL applied

Films are subtly different to the touch. With experience, it also sounds different if lightly tapped with, say, fingernails. In practical terms, the easiest way to establish its presence is to attempt to mark it - any convenient coin will serve the purpose.

- 'Novice' vandals will detect a film with a little thought and even less effort.
- 'Expert' vandals will know immediately.

4.1.2 If the film has been ANYTHING LESS than well applied

(a)	Trapped air	Air between the film and the glass – showing as small 'blisters'. Easy to get during application, and then quite difficult to remove.
(b)	Trapped dirt	If the glass surface is not perfectly clean before film application, specks of dirt lift the film off the glass and show as blisters - often hard to avoid on new glasses, almost impossible to avoid on older glasses.
(c)	Film edges	Application instructions say that the film should be cut 1-2mm from the glazing - even assuming these are cut straight this edge is quite easily detectable.
(d)	Irregular edges	If the film is not cut straight, edges are very easily detected.
(e)	Fine grazing	If the applicator used to "spread" the film is marked or too hard, it will leave

lines in the surface of the film, any one of which would be completely un-noticeable, but en-masse, are give-aways.

(f) Adhesive ridges — If the process of application has been unsteady, it is possible to create marks in the adhesive itself.

(g) Marked film — If the film has been damaged, and it is un-noticed prior to application, the film will be very evident once it is on the glass.

4.1.3 Silk screen printed glasses

However well the film is applied to printed glasses, the film will always be evident at the margin of the printed and unprinted areas. The depth of the ink is sufficient to create an air bridge that will be clearly visible. This will be a particular problem with glasses that have a series of dots printed along the margin. The film will stick to the dots – the gaps will become an area heavily populated with blisters.

4.2 Noticeability **ONCE MARKED**

- The obvious indicator is the worm-like scurf that is often created as the film is scratched. The scurf leaves a giveaway residue either adhered to the film, or if fallen, on the cill.
- There is little difference along the line of the mark. Depending upon the width of the marking instrument, it is possible to create broad marks that are difficult to create on glass.
- It is therefore easier to create "effects" on film than it is on glass. Once known, the effects are obvious indicators.

5 DO ANTI-GRAFFITI FILMS OFFER BETTER PROTECTION AGAINST OTHER TYPES OF GRAFFITI?

5.1 Paints and inks – Probably NOT

- Glass is impervious. All marks are on the surface.
- No known anti-graffiti solvents mark or damage glass.
- Because of the immense hardness of toughened glass, as a last resort, marks can be shaved-off the surface of the glass with sharp blades (held at an acute angle).
- Films are, relatively speaking, soft - even the hard coated films.
- PSVG has no experience or data as to whether or not anti-graffiti films will absorb and retain dye.
- We do not know whether all the films are susceptible to anti-graffiti solvents - but it is unlikely. The solvents will attack and dissolve the films' adhesives.
- We do know that they cannot be shaved with blades – the blades cut into the film.

Films could not perform better than glass against attack by inks or paints; it is only a question of how closely they can emulate the performance of glass.

5.2 Acids – YES

- Glass is dissolved by hydrofluoric acid (once used to mark transport glass with its quality standard; still occasionally used to etch registration numbers on car windows).
- Compounds containing the acid are readily available to hobbyists for glass decoration.
- Needless to say, vandals in the US first discovered the compounds, and acids are now offered for vandalism use on the Internet. They have already been used by vandals in London.
- Glass has no defence against such compounds.

Polyester films are totally resistant to hydrofluoric acid.

6 DO 'ANTI-GRAFFITI FILMS' CONCEAL EXISTING GRAFFITI ?

Some films are claimed to be able to mask some etched marks that are already on the glass to which they are to be applied. This is possible, but limited. To be precise, the films cannot do so, but their adhesives could.

Glass works because it does not interfere with the frequency of the light-waves passing through it – and because the frequencies are unaltered, glass is "transparent".

- Scratches on the surface of glass interfere with light frequencies, and they become visible because they are the sites where light does NOT pass through unaltered.
- It will be appreciated that since the films were specifically developed to not interfere with light frequencies, the film manufacturers use adhesives with similar qualities.
- Depending on the 'depth' and viscosity of the adhesive, it is possible for the adhesive to "fill" the lighter scratches on the surface of the glass. Because it is optically correct, the adhesive corrects the light-waves, and the scratches appear to disappear.

- In PSVG's experience, the marks have to be very light marks, and it is suggested that operators experiment with their chosen material before relying on this remedy.
- The downside of such adhesives:
  - They make the films themselves harder to remove.
  - They invariably leave a residue on the glass. The residue is not easily removed, and can be very difficult to remove if the film has remained on the glass for a long time.

7 ARE 'ANTI-GRAFFITI FILMS' EASY TO APPLY?

They are not difficult to apply but definitely do require an acquired skill.

7.1 Skill levels

- A suitably patient, conscientious and dexterous person can be trained sufficiently well in a day to be competent to undertake work without further supervision.
- With 2 weeks experience, such a person will acquire the necessary skills to become an "expert".
- It is possible to apply the film single-handed, but PSVG would not recommend that an operator planned on that basis. A second person greatly speeds up preparation, and provides an essential pair of extra hands when the film is being pulled off its backing.

7.2 Surfaces to which the films can be applied

- Films are most easily applied, and are only really practical, for flat glasses.
- The films can NOT be successfully applied (regardless of skill levels) to glasses curved on both axes, however slight the curve on the second axis.
- A skilled person can successfully apply the film to a glass curved exclusively on one axis.

7.3 Preparation of the glass surface

- The surface needs to be very thoroughly cleaned of all residues that might interfere with adhesion or leave foreign objects on the surface of the glass. Clean hands are essential.
- On a new glass, a mild detergent solution is adequate, but it is also advisable to 'shave-off' the glass with a sharp blade held at an acute angle.
- On installed glasses, sufficiently thorough cleaning will be a major exercise. A detergent solution may suffice, but it may be necessary to resort to proprietary solvents. 'Shaving-off' is invariably essential.
- It is imperative to ensure that there are NO foreign objects on the glass prior to application – however small. Even a speck of dust is sufficient to create an air-bridge between the film and glass that will show, very obviously, as an air-blister under the film.
- 'Cleansing' (replacing already marked glasses).

  Many film providers will make a (valid) case for "cleansing" the vehicle of existing graffiti before any film is applied. This is to avoid encouraging graffiti on a newly filmed vehicle. Generally speaking, this means replacing all marked glasses with new. It is possible to obscure very light marks with the adhesive on some films (see 6. above).

7.4 Preparation of the film

- If not supplied cut to shape, the film should be cut to size before it is removed from its backing.
- Film providers recommend that film should be applied to within 1-2mm of the glazing.
- Ideally the film should be pre-cut to the exact shape of the visible glass. In practical terms, this is not always possible given variations in aperture size, and variability in glazing.
- Creation of an approximate size is possible by holding the film up to the aperture and cutting slightly oversize. An experienced person can cut to almost ideal size. Oversize film can be trimmed.
- It is absolutely essential that trimming blades are very sharp. Unsurprisingly, the films have a capacity to blunt blades very quickly. Apart from slowing down application, anything less than a very sharp blade can pull and tear the film. Stainless steel blades are recommended.
- No other film preparation is necessary.

7.5 Applying the film

- The ambient temperature affects application. In PSVG's experience the preferable range is 18° - 25°C. Application should be avoided in extreme temperatures.
- It is better to work in a still-air environment - drafts are likely to bring dust particles into contact with the film adhesive and/or the cleaned glass before application, and these will create air blisters.

- The film is easiest applied 'wet':
  - As the film is peeled off its backing it should be sprayed with a fine mist of a very mild water-detergent solution (which helps breaks down the surface tension in the droplets). This stops the film sticking to itself before application (if the film does self adhere, it is virtually impossible to save the material). The water also has the very important role of dispersing film static and, therefore, the attraction of dust particles. For this reason, it is also recommended that the face (non-adhesive side) is also sprayed with mist.
  - The glass should also be sprayed with a fine mist.
  - The film may then be 'floated' onto the surface of the glass. The water stops the film adhering on contact and gives the installer the opportunity to best position the film.
  - Once positioned, with the aid of a nylon-type purpose-made applicator, the film can be trimmed.
- Finally, the applicator is used to make continuous heavy pressure strokes from the centre to the perimeter, thereby expelling the water and any trapped air from between the film and glass.
- Once this has been thoroughly completed, depending upon ambient conditions, the minimum required adhesion will be achieved within 48 hours.
- PSVG recommends that filmed glasses be re-visited 15-30 minutes after they have been 'finished'. We have found that the films, and the water necessary for their application, have a habit of creating moisture-blisters and edge lifting that will need further use of the applicator to remove and re-fix.

7.6 Application safety warning

Given the designed-in hardness of the film, and the fact that it will have been cut with a blade, any waste material trimmed-off will have extremely sharp edges of its own. It might seem improbable, but these edges are easily capable of cutting skin if the material is accidentally pulled across hands.

8 ARE THE FILMS EASY TO REMOVE?

- No. They are usually easier to apply than they are to remove.
- But, they are much easier to remove than glass – this IS the reason for using sacrificial films.
- The films have something of a dilemma - good adhesion and easily removable are performance opposites.
  - Easily removable means less adhesion.
  - To stick to glass, and to stay on (particularly in this application), the adhesion needs to be extremely good. And that means being less easy to remove.
  - The longer a film is in situ, the more difficult removal will become.
- The best method for removal, in PSVG's experience, is to cut the film into, say, 100mm wide strips, with a sharp blade, and then pull the strips off individually. This takes a little longer than a successful attempt to pull the film off in one go, but in our experience one-go attempts are seldom successful, anyway.
- Whatever removal technique is used, there is a probability of the film separating from the adhesive. This becomes more probable the longer the film remains on the glass. When adhesives are left on the glass, sharp blades and solvents will need to be used to remove the residue.

9 WHAT IS THE SERVICE LIFE OF THE FILMS?

- Currently, there has been no long-term exposure in a transport environment.
- Whilst the films' manufacturers do give various period guarantees, they sometimes seem limited.
- The on-public-transport-glass application is a relatively new, and possibly hostile, environment. Unlike in architectural applications, the films will be exposed to constant and rapid changes in lighting conditions; and considerable variations in temperature and humidity during the course of a year.
- There may also be some long-term difficulty arising from the 'removable' adhesive's exposure to UV and IR light. The adhesives may 'cook' in a transport application and, over time, in practical terms, might become very difficult to remove from the surface of the glass. In consequence:
  - If a long-time installed film never has to be replaced because of etched-graffiti, it might become necessary to replace the glass anyway!
  - The worse scenario - if the film/adhesive does decay and needs replacing for that reason alone, and if the adhesive cannot be removed from the surface of the glass, the glass will have to be replaced, even though neither it, nor the film, has suffered any vandal damage.
- Ironically, glass with an otherwise indefinite service life, after the application of film intended to extend its life, could end up with a finite service life.

10 THE SAFETY IMPLICATIONS ASSOCIATED WITH THE USE OF ANTI-GRAFFITI FILMS'

PSVG's research and enquiries have failed to find any published comment on the safety implications of using on-glass films. The issues seem to us to be significant, and we advise operators evaluating anti-graffiti film to consider this section carefully.

10.1 Glass used in public transport HAS to conform to regulatory safety standards

- Under UK legislation, safety glass for public transport HAS to conform to very stringent production standards. The familiar 'old' standards were BS857 and BSAU178. They have since been superseded by the International Standard E43r.
- These standards apply to both laminated glass (used for front windscreens) and toughened (tempered) glass used elsewhere in vehicles.
- Anti-graffiti films are proposed for use on toughened glass.
- Operators will already be familiar with these standards, and know how rigorously they are checked by the Vehicle Inspectorate.

10.2 The safety implications of films applied to **laminated** glass

- There are NO negative safety implications.
- There is a safety benefit:
  - Applied to the inside surface of a laminated glass, the anti-graffiti films will perform perfectly as an anti-spall film from the safety and security film group from which they have evolved. Passengers adjacent to a filmed laminated glass hit by a missile from outside the vehicle will be additionally protected by the use of an anti-graffiti film.
  - However, this benefit is of very limited practical use. Laminated glass is almost exclusively used for front windscreens that are invariably curved on each axis – the anti-graffiti films cannot be applied to them.
  - Laminated glass is seldom used in flat applications such as bus or coach sides. However, Rail Group Standard GM/TT0122 requires one laminated pane in a multi-pane application.

10.3 The safety implications of films applied to **toughened** glass

ANY material, including anti-graffiti films, applied to the surface of toughened glass SERIOUSLY COMPROMISES its safety performance.

10.3.1 What is **supposed** to happen

The productions standards require toughened glass to shatter into thousands of small regular shaped particles the instant it breaks.

- Such a break pattern is considered 'safe' because the glass is required to shatter into so very many pieces – a standard bus bay (say 800mm x 1200mm), typically, will break into a minimum of 22,000 particles.
- A rail carriage pane of similar size is expected to break into a minimum of 15,000 particles.
- This break performance is considered "safe" because when a toughened glass does break, it loses its structural integrity and shatters in a predictable way. Each particle:
  - is a small cuboid shape, and, therefore, has no long 'slicing' edges.
  - has edges that are near 90° 'corners', and, therefore, no razor-like edges.
  - is of negligible weight (0.20 - 0.25 gram), and, therefore, completely dissipates total sheet weight, such that individual particles will bounce off anything they hit.

10.3.2 What **does** happen to a filmed toughened glass

The film dramatically changes the break performance of the glass.

- Although the glass will shatter and disintegrate as required by the safety standard, the thousands of cuboid particles will remain bonded together in a single **sheet**.
- The stronger the film's adhesive, the more likely it is to hold the particles together to create a sheet.
- Anti-graffiti films **do** use strong adhesives. They **do** create **sheets**.

The behaviour of the **sheet** will be determined by the "**Compression-Tension Effect**". The effect occurs where a film is applied to ONE surface of a toughened glass. This

dramatic characteristic should be thoroughly understood by public transport operators when considering anti-graffiti films.

(a) The **Compression Effect**

- Occurs when a force is applied from the non-filmed side.
- With anti-graffiti films, this means from outside the vehicle.
- Under such a force, the shattered panel will try and collapse towards the filmed side (the inside of the vehicle).
- All the particles compress along their outermost edges on the side that is under force (the outside face of the glass).
- Given that (a) the glass particles will not compress, (b) the film will not stretch (if they did, they would be soft and therefore offer no protection against vandals), and (c) the adhesive will not let go of the particles, the force 'locks' the shattered sheet into a more rigid, stable state.

The Compression Effect will:

- Discourage the sheet from falling into the vehicle.
- Confer **safety advantages** upon passengers.

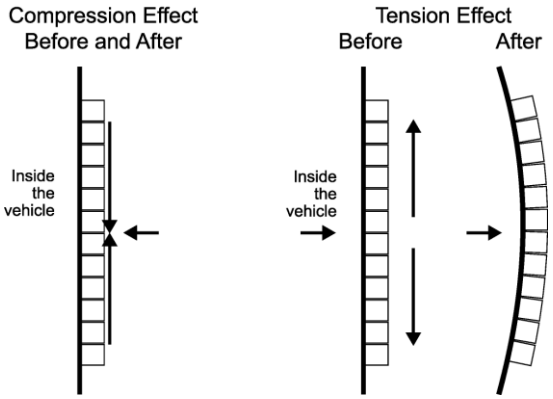
(b) The **Tension Effect**

When a non-filmed toughened glass shatters, all that is holding the particles together is the tension at the interfaces between all the individual particles. This tension prevents them shearing past one another, and the sheet falling to pieces. This is usually a temporary state. The Tension Effect (which might be more readily appreciated if thought of as the un-tension effect):

- Occurs when force is applied from the filmed side.
- With anti-graffiti films, this means from inside the vehicle.
- Under such a force, the shattered panel will try and collapse towards the non-filmed side (the outside of the vehicle).
- As pressure is applied, all the particle-on-particle shearing effect is lost. The film acts as a multiple hinge between all the particles, and converts the force into a hinge opening action thus readily un-tensioning all the particles.
- Once the force has created the hinge effect and structural stability is lost, the shattered sheet will collapse in on itself under its own weight.

The Tension Effect will:

- Mean that the sheet is more likely to fall outwards.
- Present a **safety risk** to people and property outside the vehicle.



10.4 The safety benefits created by the Compression Effect

Anti-graffiti films protect adjacent passengers by performing as an anti-spall film.

10.4.1 Anti-spall protection

Under normal operating conditions, an operator can be certain that a passenger adjacent to a shattering anti-graffiti filmed glass panel will be protected from flying shards. This is particularly beneficial with toughened glass since the tension released at breakage throws off shards at high velocity.

10.4.2 The film creates a semi stable sheet

Under normal operating conditions, an operator can be very confident that the anti-graffiti film will also prevent the small glass particles showering onto passengers.

A **non-filmed** glass in a public transport vehicle will very readily collapse:

(a) Body design is not conducive to structural integrity:

- Virtually all vehicles have side glasses on, or extremely closely aligned to, the vertical. Moreover, the vast majority of glasses are flat, and those that are not (some coaches) have an extremely shallow curvature concave to the interior.
- This means that structural integrity relies mostly upon the thickness of the glass and the inherent resistance of one glass particle to shear against another one. The "thinner" the glass, the less the particle-to-particle shearing surface. Typically, for weight considerations, double-decker buses are glazed in 4mm, single-deckers are glazed in 5mm, and trains 6+mm. The 4mm thick particles of a vertically glazed flat glass offer very little resistance to shearing.
- By way of reverse illustration: typically, cars are glazed in 3mm, but because of the smaller panel size, the greater curvature concave to the interior, and the greater inclination away from the vertical, shattered car windows are often positively difficult to push in (but easier to push out).

(b) Body motion provokes structural failure

Almost by definition, the panels most likely to be broken are large. $1m^2$+ is commonplace. The larger the shattered panel, the more likely it is to fail structurally. The panels are further encouraged to fail by:

- Low frequency body shudder caused by idling diesel engines.
- The bump and sway from road surfaces (especially along the kerbside which buses, in particular, traverse).
- The sway and jerk of railway carriages, and in particular, the "pulse effect" of trains passing one another, and in and out of tunnels.

10.4.3 Resistance to penetration

Many side glasses are broken by vandals throwing missiles at vehicles. A passenger adjacent to a glass shattered by an incoming missile is not only likely to be showered by shards and glass particles, they are also likely to suffer injury from the missile itself.

The anti-graffiti film will not only keep the particles in sheet form - because of the Compression Effect - it will also create a high level of resistance to penetration where a non-filmed sheet will have virtually none.

PSVG's destructive tests have revealed that an anti-graffiti filmed glass will also afford passengers significant protection from missiles thrown at the glass panel:

- In comparative tests, a shattered anti-graffiti filmed 4mm glass required 15 times more force to be pushed into a bus than a shattered non-filmed glass.
- It is not practical for PSVG to predict the degree of protection. Even if a regulatory authority were able to do so, an operator could not rely on a random missile's size/weight/speed/direction conforming to previously quantified standards.
- However, it is clear that the protection is significant.

- During PSVG testing, a house brick thrown with force at the approximate centre of a 0.8m^2 glass panel, broke, but failed to penetrate a filmed glass panel.

This safety benefit will be of particular interest to operators whose passengers have suffered (or may suffer) injury from projectile assaults on their vehicles. The use of films might also mitigate against personal injury claims arising out of such attacks.

10.4.4 An **operational** rather than safety consideration

The vehicle operator may consider that there may be additional operational benefits in so far as a road vehicle with a filmed shattered glass panel can more easily "limp" through the balance of its route. If, on the other hand, it is an operational requirement that shattered glass should be immediately removed from its aperture, the filmed shattered glass panel might be considered to be something of a disadvantage.

10.5 The safety compromises, risks and dangers of the Tension Effect

The use of anti-graffiti films so **dramatically** changes the break performance of toughened glass, they seriously compromise the safety benefits which the statutory regulations require the glass to meet.

Operators should very carefully consider these changes in break performance before using films, and thoroughly evaluate the risks and benefits against the objectives they are trying to meet.

10.5.1 Physical characteristics of the sheet.

The sheet created by the film has almost totally opposite characteristics to those intended, and required, for toughened glass in public transport applications:

- Regulations require toughened glass to break into small particles such that each particle is a small cuboid shape – that is, it has no long (slicing) edges.
- **The shattered sheet will have long slicing edges.**
- The particles in a shattered toughened glass are intended to separate, and each particle will have edges that are at near right angles to one another – that is, no razor edges.
- **The sheet will have edges at uncontrolled variable angles - many of which will be razor like. Because the particles will be randomly arranged, the razor edges will combine to make sawing edges. The Tension Effect will cause the sheet to fold around itself hinged by the film creating long sawing edges.**
- Each particle is intended to be of negligible weight (0.20 - 0.25 gram), totally dissipating the weight of the glass into relatively harmless particles.
- **The sheet represents no weight dissipation at all; instead it is a heavy, "floppy" object with very sharp edges.**

A shattered sheet of toughened glass created by the application of anti-graffiti film is potentially, on all objective and subjective measures, a dangerous, extremely difficult to handle, and frightening object.

10.5.2 When the sheet falls into the vehicle

- The tension-effect will cause the glass sheet to "drape" itself over whatever solid object(s) it first comes against.
- If the object is a passenger, they will be protected from the face of the glass by the smooth surface of the film.
- However, the perimeter edges of the sheet will be extremely dangerous – the film will hold a line of cuboid particles all around its perimeter. The razor sharp saw-like edge will be desperately capable of scoring, cutting and ripping anything it passes across. The implications for passengers, and operational staff, are obvious.

10.5.3 When the sheet falls out of the vehicle

If the sheet is going to leave the aperture of its own volition, the Compression-Tension Effect pre-determines that the sheet is going to fall outwards. When it does, at the very least it is a dangerous object. There are a number of scenarios:

(a) If the vehicle is stationary:

- The sheet is going to fall from the lower deck of a double deck bus, or from a

single-decker. It will have a fall of at least 1.75m. Because of the Tension Effect, the sheet is likely to start folding in on itself.

- If it falls from a vehicle with a higher glazing line (e.g. coach, train or bus upper deck) it will have more fall during which to fold.
- As it folds, whilst it gets no heavier, the sheet reduces its size and will strike the ground with greater point impact.
- If the sheet lands directly on the ground, it is either in the gutter, lying track-side or in the middle of a roadway. From there, the sheet can NOT be picked up by unprotected hands. It cannot be swept, it can only be pushed around. As it is pushed, it will contort and create yet more razor-saw edges. It cannot be put in anything other than an armoured bag or metal receptacle.
- It is, without reservation, a severe public danger.
- If it doesn't first hit the ground, but say, an adjacent car, it will cause severe damage.
- If it hits a pedestrian, it WILL inflict extremely serious injury, the severity of which can be imagined.

(b) If the vehicle is moving:

- It becomes an object of extreme danger. It is heavy, and as it falls downward through the air at travel speed, it will twist and contort opening any number of razor-saw edges.
- The greater the height from which it falls, the faster the speed of the vehicle from which it fell, the more dangerous it becomes.
- Whatever it hits is going to be very severely damaged.
- If it hits a person, in brutal objectiveness, it is capable of killing them.
- Even if doesn't fall and directly hit a pedestrian's head, face, back or chest, but was, to say, slide along a pavement or platform at 20-25mph, its potential for causing severe injury to feet and legs can be imagined.

(c) The potential to create a lethal missile

- Non-filmed glass panels are already being broken by on-board vandals. When they are, there is a "gratifying" bang and an instant fall-to-pieces mess, albeit with some danger of actually getting hurt.
- It is conceivable that an anti-graffiti filmed glass could generate another new act of vandalism. A filmed glass is a different opportunity:
  - still a "gratifying" bang,
  - but no fall-to-pieces mess to alert anyone,
  - no danger of getting hurt,
  - but a potential weapon of extreme destruction.
  - The filmed glass will remain in its aperture until the vandal chooses to push it out on to some hapless victim – perhaps a car, or even a kerbside pedestrian.
- The fact that knowingly committing such an act may amount to a police charge of actual or attempted murder may, of course, deter them.

11 THE USE OF ANTI-GRAFFITI FILMS ON DESIGNATED EMERGENCY EXIT GLASSES

Notwithstanding that the following applies to any glass filmed with an anti-graffiti product, special attention should be given to the implications of filming designated Emergency Exits.

- The film will not prevent the glass from being broken.
- Passengers will have no more difficulty breaking a filmed glass than they would have breaking an un-filmed glass – especially with the hammers provided for the purpose.
- However, "what do I do next?" will be very much less obvious to passengers in an emergency.

11.1 An un-filmed Emergency Exit glass

- If the break hammer does not punch a hole, or obviously misalign the particles around the point of impact, it will still be obvious to the passenger as to what is supposed to happen next.

- The shattered panel will be unstable and 'wobbly', and with just a little encouragement, it will collapse and fall out of the aperture. Passenger may well have to knock particles from the perimeter to enlarge their exit route, but they will quickly realise what they are supposed to do.

11.2 A filmed Emergency Exit glass

- The glass will shatter but will stay in place. Hitting it repeatedly with the hammer, a shoe, handbag (or anything else about their person) will have little effect. The apparent resistance of the emergency exit to let them escape might cause (or heighten) panic in a passenger.
- To effect an escape, a passenger will need to exert sustained pressure on the centre of the shattered sheet until it falls out as a composite whole. It is not difficult to achieve the required pressure, but it is best applied from a braced position. Theoretically, a passenger not bracing themselves could follow the sheet out of the hole it created.
- Because of the film on the inside surface of the shattered sheet, a filmed Emergency Exit is much less likely to injure a passenger than an un-filmed glass. In fact, a passenger could push the shattered sheet out of its aperture with their bare hands, and still not suffer injury.
- When it does leave the aperture, it will leave it in one go, and, if properly glazed to within1-2mm, will almost certainly take with it all the edge particles from out of the glazing rubber. If it is a direct glazed Emergency Exit, it can be removed in the same way but it will leave ragged glass particles in the bonding material around the perimeter (but no more so than a un-filmed bonded glass).

  A filmed Emergency Exit does offer safety advantages in an emergency escape situation:

  - It will protect passengers from shards and particles.
  - It will push out in one go and provide an instant, clear, maximum size exit route.

If an operator intends to film Emergency Exits, then the VI (for road) and a VAB (for rail) should be consulted first. Subject to their advice, PSVG emphatically recommends that clear "How to Use" instructions be posted on, or adjacent to, the exit. We note, though, that this is also tantamount to advertising the presence of anti-graffiti films on the vehicle.

12 SAFETY BENEFITS AND RISKS VARY BETWEEN APPLICATIONS AND GLAZING METHODS

The safety performance of anti-graffiti filmed glasses varies (often significantly) depending upon how, and to what, they are applied. The variables are:

12.1 Using anti-graffiti films on laminated glasses

- Unlike toughened glass, there are no safety compromises, risks or dangers when using anti-graffiti films on laminated glass.
- The structural integrity of laminated glass is always maintained by the plastic film bonded to the two glass sheets during manufacture. The centre film creates opposing compression-tension effects in the each glass sheet.
- The only safety issue is enhancement – the anti-spall effect of the film.

12.2 How close to the edge of the glass the film is applied

- PSVG tests indicate there is a significant difference in a glass panel's break-performance depending upon how close the film is applied to the edge of the glass, and how the glass is fitted to the vehicle.
- Simply, the nearer the edge of the film to the edge of the glass, the better the film's ability to keep a shattered sheet in its aperture.

12.2.1 1-2mm from the glazing.

To be sacrificial, the applied film must be capable of removal. Film providers recommend a gap of 1-2mm from the glazing because:

- It makes the edge of the film less obvious/detectable;
- It reduces the chance of any contamination at the glazing margin causing the edge of the film to lift of its own accord (and thereby offering itself as an opportunity for peeling-back by vandals).
- It is still possible to lift the edge of the film for re-filming.

12.2.2 PSVG tests indicate that gap width is far more significant and critical for **safety** reasons:

- Filmed to within 1-2mm of the glazing (as recommended)

  Compared to a non-filmed glass, such an application required 7 times more force to push the shattered sheet out of its aperture. Disregarding the potential safety compromises of a filmed sheet falling from the vehicle, this clearly provides a safety benefit from filming.

- Filmed less accurately (to, say, 5mm+ of the glazing)

  Compared to a glass filmed within 1-2mm, such a sheet required 40% less force to push it out of its aperture. Extrapolating from PSVG tests, the greater the distance of the film edge from the glazing, the easier it becomes to push the shattered sheet from its aperture.

  The greater the gap, the less able the film is to confer the safety benefit of increased sheet stability, and the more likely the film is to fall outwards from its aperture.

- Filmed to the edge of the glass (and into the glazing)

  Compared to a non-filmed glass, such an application required 9 times more force to push it out of its aperture (about 30% more than if filmed to within 1-2mm).
  Glazing to the edge of the glass enhances the safety benefit provided by the film, but **removes the sacrificial quality** (the glass has to be removed to be re-filmed).

12.2.3 The significance of the particles along the perimeter of the film

This change in the sheet's break-out performance is due entirely to the location of the glass particles at the perimeter of the film.

- When filmed within 1-2mm of the glazing, the film is also stuck to glass particles retained by the glazing method – more force is required to either pull these particles out/off of the glazing, or to break their bond to the film.
- If the glass is filmed 5mm or more away from the glazing, the glass particles along the film's perimeter are **not** retained by the glazing method, and the sheet can be more easily removed from its aperture.
- Conversely, if the glass is filmed to its edge, more force is required to remove the sheet from its aperture because ALL the particles at the film's perimeter are located inside/on the glazing – and ALL need to be pulled out/off before the sheet can leave its aperture.

12.2.4 Conclusion on filming up to the glazing.

Given that the film is, by definition, going to create a safety compromising sheet of shattered glass, it is important to film the glass accurately to within 1-2mm of its glazing in order to minimise the probability of the sheet leaving its aperture.

12.3 Differences between rubber and direct-glazed glass panels

12.3.1 Rubber glazed installations

In 95% of installations, it is possible to see, and work up to, the edge of the glass as it enters the glazing rubber. It is therefore possible to film within 1-2mm. (The remaining 5% have interior trim finishers that conceal the glazing rubber.)

12.3.2 Direct-glazed installations

In these installations, the glass is bonded to the body structure. With such installations, additional issues need to be considered before a filming decision is made:

(a) Filming within 1-2mm of the glazing

- Even when no trim finishers are used, the glass-to-body bond is not always visible from inside the vehicle. In consequence, it is not always possible to film within 2mm of the bond.
- Even where it is possible to see the edge of the bond, the edge of the bond is often an irregular margin, and it could be extremely difficult to accurately trim the film.
- Were an operator prepared to forego the sacrificial benefit of the film, it is not practical to pre-film a glass prior to installation. In these circumstances it would be the film, and not the glass, that was then bonded to the body. Even were the bonding agent to properly adhere to the film, the strength of the glass's fix to the vehicle would only be

as strong as the film's adhesion to the glass, and this would compromise structural integrity where direct-glazed glasses are used for body strengthening purposes.

- If a direct-glazed glass was to be filmed, it might easily have to be filmed at least 10mm (and as much as 20-30mm) away from its glazing. An operator intending to film such glasses needs to first review actual in-vehicle glazings, before being able to make an informed assessment of a shattered sheet's ability to remain in its aperture.

(b) The effect of an all-sides-rigid aperture

- When an anti-graffiti filmed shattered sheet in a rubber glazed installation tries to leave its aperture outwards, the bowing effect in the sheet as it starts to move outwards becomes a turning moment at the glazing rubber. Because the rubber is pliable, it twists outwards with the sheet, and helps ease the sheet out of its aperture.
- In a direct-glazed application, successfully filmed within 1-2mm of the bond, the shattered sheet can not get a turning moment from the all-sides-rigid glass-to-body bond, and the shattered sheet will be (comparatively) better retained in its aperture.

(c) Black silk screen printing

- To protect the bond from UV light (and to conceal the irregular and unsightly line of bonding material from view), glasses that are to be direct-glazed to the aperture have their perimeter printed with a black ink ('masked'). (There are a few rubber glazed applications that also use masked glass).
- If masked glasses are correctly manufactured, the ink is a ceramic-type that becomes fired-on to the glass at the extremely high temperatures used during the toughening process. In addition to its functional anti-UV properties, such masking is also regularly used to create decency zones and other design features on an ever-increasing number of vehicles.
- Anti-graffiti films adhere to glass very well. They are not so successful at adhering to the less smooth surface of ceramic inks.
- In consequence, filming to the visible edge of a masked direct glazed glass will mean applying the film to ceramic inks. The resultant lower level of adhesion means that:
  (i) the film can be more easily peeled-back by vandals;
  (ii) there is a decreased probability of the shattered sheet being retained by the edge particles (even assuming the film had been applied 1-2mm from the bond).
- If a masked glass is filmed 10mm+ from the bond, the relative lack of adhesion does not further diminish sheet retention.
- Not all masked glasses have correctly fired-on ceramic-type inks. Some glasses are supplied with inks applied after toughening; others are supplied without masking at all and the installer applies them immediately prior to glazing. If any of these glasses are filmed, adhesion to the masking will be very poor, and the problems will be worsened.

12.4 The influence on performance of an adjacent frame (such as a hopper or slider)

12.4.1 When a glass is filmed within 1-2mm

- The shattered panel derives rigidity along the edge adjacent to the frame that it cannot get from a rubber gasket. This slightly improves the sheet's ability to stay in its aperture.
- However, there is the possibility that the falling sheet can also pull the frame out of the aperture. The framed unit is always heavier than the glass beneath and represents a blunt-object hazard to whatever it may fall on.

12.4.2 If the glass is filmed 5mm+ from the frame

- The frame affords no additional rigidity to the sheet.
- The sheet has no more or no less influence on the frame's ability to stay in the aperture than a shattering non-filmed glass.

12.5 Double glazed apertures

Double glazed panels are seldom used in buses, common in coaches, and almost the norm in railway carriages. Anti-graffiti films would be applied to the inner pane and in these applications, the film would be almost entirely free of safety-compromises.

12.5.1 If the outer panel becomes shattered

If a missile is thrown at a double glazed panel, it is almost certainly only going to shatter the outer panel. If it does, the inner panel remains intact and passengers are un-compromised. If the first missile does break both the outer and inner panels (or a second missile breaks the inner), the passengers are subjected to the same protection (and risks) as if the aperture had been single glazed.

12.5.2 If the inner panel becomes shattered

The inner panel is very unlikely to fall into the vehicle. It will be afforded wind protection (and pulse protection in the case of railway carriages) by the intact outer panel. It would be very difficult to 'bounce' the inner panel out of its aperture by pushing outwards since its movement would be restricted by the cavity between it and the intact outer panel. It will be impossible for the shattered inner panel to fall (or be pushed) out of the vehicle unless the outer panel is also broken.

12.5.3 Reduced importance of filming within 1-2mm of the glazing

With single glazed panels, it is important to film within 1-2mm of the glazing to maximise sheet retention. In a double glazed application, the shattered inner sheet is constrained by the intact outer panel, and therefore the importance of filming within1-2mm of the glazing, is substantially reduced (if not totally removed). Similarly, only being able to film up to the visible edge of a direct (double) glazed panel is also compromise-free.

12.6 Whether or not the glass has an exterior film (e.g. all-over signage)

Where a film is applied to the outside face of a glass panel, the Compression-Tension Effect works with reverse implications:

12.6.1 If a vehicle already has all over external signage covering body and glass panels

Whilst passengers will be unprotected from shards, the shattered panel will, in fact, be secured in its aperture by the film being continuous from the glass perimeter onto the body panels of the vehicle. The shattered panel:

- Will not fall in (but might project more shards as particles grind on one another).
- Will not fall out. In fact it would be extremely difficult (if not impossible) to push the panel outwards at all.

If an anti-graffiti film were applied to a vehicle with all-over signage, the two films would together offer ultimate protection.

12.6.2 Ultimate protection

If an anti-graffiti film were to be applied, and:

- The vehicle already had all-over external signage; or
- The anti-graffiti filmed panels also had a retention film applied on the outside.

  (A retention film is a second film applied to the exterior face of a glass).

The two films would each subject a shattered panel to a Compression-Tension Effect. Each film would create an effect that opposed the effect of the other.

- The panel would be something of a "reverse laminate" - instead of being glass-plastic-glass, it would be plastic-glass-plastic.
- Once shattered, it would be extremely rigid, and would be extremely difficult to be even forced out of its aperture. If the retention film on the outside was to run to the edge of the glass (either into the rubber glazing, or over the area of the direct glazing bond) it would require considerable force to remove it from its aperture.

Whilst the application of two films would be a more expensive anti-graffiti solution, it would be a solution almost entirely without risk to passengers, and to the public and property outside the vehicle. But even this lowest risk solution would have problems:

- retention films are very unlikely to survive the rigours of the nylon brushes, road/track grit, and detergents used in bus and train washes.

Note – retention films should NOT be applied to emergency exit glasses.

Summary

1 The sacrificial films currently being offered as a defence against etched graffiti are not new, and have been used in architectural applications for many years. The films are technically reliable and very sophisticated products. They are extremely "tough", and will generally afford a high level of protection against scratching on the surface of the glass to which they have been applied.

2 In some respects they have similar safety performance characteristics to anti-spall films. Anti-spall films were designed to contain glass shards thrown off glass at high-impact breakage. The anti-spall properties of anti-graffiti films offer transport operators considerable safety advantages.

3 Anti-graffiti films do not prevent etching, although it is sometimes claimed that they will discourage it. There is no firm evidence to substantiate this claim. Conversely, it is also argued that the films' physical properties will facilitate (and therefore encourage) more vandalism. There is no clear evidence of this either.

4 Assuming that the films are only applied up to the visible edge of the glass, a film that has been damaged can be peeled-off and replaced with new. Removal is harder than application.

5 Replacing a vandalised sacrificial film can be easier, quicker and cheaper than replacing glass. However, there are many practical considerations which make the whole issue worthy of a thorough future-logistics evaluation as well as a cost-benefit analysis.

6 The area of material required to "protect" a fleet is considerable. If an operator accepts that anti-graffiti films do offer protection, it is logical to protect all glasses. Since the investment would then become substantial, more vulnerable glasses are selected for filming. This may be sufficient, but it may displace etched-graffiti onto unprotected glasses.

7 The films are not difficult to apply, and the required skills can be learned quickly by staff with the right aptitude. Thorough preparation of the glass surface is very important.

8 A considerable reduction in initial investment can be achieved by training garage/depot staff to apply the film. Self-application is the only realistic way of making the ongoing film maintenance an economic proposition, and the very best way to achieve the fast replacement times required for the effective use of films.

9 The use of anti-graffiti films may help to control glass-etching. They may also help to reduce the cost of removing such vandalism. There may also be accumulating long-term costs. These difficult assessments need to be made by operators against the background of their problem. PSV Glass ('PSVG') cannot authoritatively comment on these issues.

10 Whilst the films have their obvious anti-graffiti use, there appears to be only passing consideration of their secondary benefit - the ability to afford passengers protection from projectiles thrown at buses and trains. It seems to PSVG that this benefit could, in fact, be the primary reason for some operators to use the films.

11 However, PSV Glass advises the industry that there are safety implications arising from the use of anti-graffiti films, some of which are very significant.

12 PSV Glass (or any of its trading companies) cannot accept any liability resulting from any damages caused as a consequence of a film either applied and/or supplied by PSV Glass to a glass that subsequently fails or becomes detached from its position in the vehicle.

13 Applying anti-graffiti films will so dramatically alter the break performance of toughened glass as to render it incapable of meeting the safety standards required by BS857, and the Road Traffic Construction and Use Regulations (1986). This change in performance presents both benefits and risks.

14 The safety benefits are that the films will protect passengers from glass shards thrown off toughened glass at the instant it shatters. They will also increase a shattered panel's ability to stay in its aperture, and therefore also reduce the risk of passengers being showered with broken glass particles and being injured by incoming vandal-thrown projectiles.

14 Due to a mechanical phenomenon known as the "Compression-Tension Effect", safety risks arise from the fact that the shattered panel will more likely to fall outwards from the aperture (rather than inwards). When (and if) it does fall, it will leave the aperture as a single and heavy shattered sheet of broken glass that has NONE of the properties designed-in by the toughening process, and as required by BS857. The object leaving the aperture will be easily capable of rendering serious damage and injury.

15 Whatever the merits and demerits of anti-graffiti films' abilities to combat glass-etching, operators are advised to also carefully consider the balance between the safety benefits and the safety risks from the use of films applied to the inside face of toughened glass on public transport.

Conclusions and Recommendations

PSVG is unable to draw any supportable conclusions in respect of anti-graffiti films' ability to reduce etched graffiti. Whilst it is true that it is easier and cheaper to replace a removable film than it is to re-glaze, the use of films raises many complex issues. Even discounting the unproven theory that the films will encourage vandalism, it is clear that the use of films will require a consistently well-managed maintenance programme. This could represent a substantial external cost if not undertaken by operators themselves. Neither PSVG, nor anyone else, are able to definitively comment on the in-service-life of the products. There does seem to be the potential, at least, for films to build in an unknown future maintenance cost even where the film remains free of graffiti.

Any conclusion on the use of anti-graffiti films on glass installed in public transport inevitably ends up as being a matter of personal speculation. Whilst PSVG can see more merit in applying films to some glasses and less merit in applying them to others, we can make no recommendation as to whether or not an operator should use anti-graffiti films. The decision to use will be dependant upon the extent (i) of an operator's etched-graffiti problem, and (ii) their assessment of other vandal problems for which the film also has real benefit. Against these, the operator will need to consider the short and long-term costs, and the safety benefits and safety risks associated with the use of the films. If an operational decision is made to install films, PSVG makes the following recommendations:

1 For materials handling reasons, we suggest operators use films that are thicker, and films that can be pre-cut to approximate shape and delivered as flat sheets.

2 If a hard-coated film is available, and it is no more expensive, we suggest that it be chosen.

3 Train your own staff to apply the film. Application is not difficult, and staff with the right aptitude can learn the required skills quickly. The use of already employed personnel will:
   (i) very substantially reduce the cost of anti-graffiti filming the fleet;
   (ii) make the ongoing maintenance of films an economic proposition;
   (iii) give the shorter replacement lead-times that the effective use of films require.

4 Only attempt to apply the films to flat, side and rear facing glasses (which will normally be toughened).

5 If an operator wishes to film designated Emergency Exits, they should first consult the VI (bus and coach) or a VAB (rail). If permitted to film, 'How to Use' instructions should be posted on, or adjacent to, each filmed exit.

6 Always film to within 1-2mm of the glazing (much less critical with double-glazed panels).

7 Try to avoid applying films to direct-glazed panels unless it is possible to see and film within 1-2mm of the bond. (Not a requirement for double glazed apertures.)

8 If road transport operators, in particular, have concern about the consequences of shattered sheets falling outwards, they should consider applying a retention film to the exterior face of all anti-graffiti filmed panels. (Do NOT apply a retention film to emergency exit glasses.)

9 Rail operators need to satisfy themselves that any film applied to glass installed in rolling stock complies with:
   (i) Smoke emission and toxicity test to BS6853 annex D8.4
   (ii) Flammability to BS476, parts 6 and 7 (minimum Class 2)

   In addition, prior approval for installation should be obtained from your Train Engineering Support company.

10 If the deterrent effect arising from the use of films is to be optimised, a formal 'film survey and maintenance programme' is essential. Endeavour to log bay location and the date of application (and all replacements) to establish usage patterns. If an operator uses more than one film type, or more than one third party installer, it is imperative that the log records which is which – films are indistinguishable once applied to the glass. If logs are not kept, vital interpretive information will be entirely lost.

11 Consider advising your insurers that you intend to (or are already using) the films. It may be prudent to make them aware of the safety benefits afforded to passengers, and the potential risks. (In the event of a possible future injury claim from passengers (or the public), changing the break performance of toughened glass by applying films may be taken as an opportunity to refute the validity of a policy claim.)

12 Consider whether you should consult senior management before making the decision to apply a film to the inside face of any glass on any vehicle in your fleet. Under proposed Government legislation, it is they who will be held personally liable for the proposed new offence of "corporate negligence".