

PATTERN AND IRIDESCENCE

HANDBOOK ON ANISOTROPY EFFECTS ON GLASS FAÇADES

SEPTEMBER 2023



FLAWLESS FAÇADES

DESIRE AND REALITY

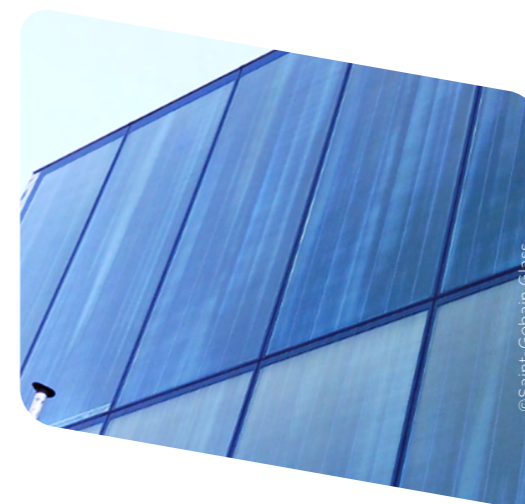
Glass façades bring the interior and exterior together, ensure natural light and a striking appearance. They offer countless opportunities to make an architectural statement, flaunt individuality and provide even the most daring structures with a touch of extravagance.

That's because glass, and heat-treated glass in particular, provides a unique response to the demands that architects are placing in façades today. Glass is not only timeless, but also offers a whole host of benefits: both transparent and robust, it lets daylight flow into the building and provides protection from noise or sunheat, among others. Thanks to its processability and versatility, it also serves as a construction element to create large urban structures with a perception of lightweight and allows buildings to blend with their environment.

That makes it all the more frustrating when unsightly effects occur in the form of optical distortions, patterns and iridescence on glass façades, compromising the building design and aesthetics.

Distortions may result from deformations and unevenness in the glass that develop during production and installation; anisotropy effects are the result of inhomogeneity, typical of heat-treated glass. They do not impact glass performance, so are not considered a defect, but rather an undesired side effect of the tempering process. Anisotropic effects cannot be prevented entirely, however, they can be reduced significantly to better meet aesthetic requirements in the façade.

Saint-Gobain Glass has dedicated itself to this topic since 2015 to understand the causes of anisotropy and its effects, develop knowledges to limit the eventual optical phenomenon, inform project owners and architects of the issue and help to attain tailored anisotropy quality.





To visually expand the building and blend it with the environment, all the glass panes need to be flawless throughout the façade. It is requested to prevent unsightly optical effects such as light or dark stripes, spots or rainbow-coloured iridescence. However, these undesirable visual effects can occur with heat-treated glass, disrupting the planned visual appearance. Depending on their intensity, such anisotropy effects can appear as leopard spots, shimmering or quench marks.

THE CRUX OF THE MATTER

THE DEVELOPMENT OF VISIBLE ANISOTROPY EFFECTS

The glass processing and its interaction with light are responsible for anisotropic effects in façades. Patterns can be visible when polarised light meets inhomogeneous and anisotropic residual stress in heat-treated glass.

ISOTROPY VS. ANISOTROPY: in its raw form, float glass is an isotropic material – like water, honey, oil and air...- whose physical properties are the same (iso-) in all directions (-tropy). In contrast, certain characteristics of anisotropic materials such as wood, most metals, slate, sugar and salt change depending on the considered direction.

Heat-treatment process conditions such as pressure and temperature can make glass anisotropic – as is the case, for example, with the tempering process, during which numerous factors affect the homogeneity of the glass.

IRIDESCENCE = INHOMOGENEITY + POLARISED LIGHT: glass structural non-uniformity has an effect on how it will interact with light. The way it is passing through, is reflected and is absorbed varies through different areas of the material. As a result, we sometimes see the so-called “iridescence” of heat-treated glass when we observe it under natural light.

It does not happen all the time: the light must be polarised to reveal quench marks. This happens, for instance, when the sky is blue or when sunlight is reflected on a close-by water, snow or ice surface, or another building. If you wear polarising sunglasses, the marks appear even more intense!

THE SOURCES OF INHOMOGENEITY: These optical phenomena are the result of the manufacturing process for heat-treated glass, which does not affect uniformly the glass pane.

To achieve the desired level of strength, the glass first has to be heated and then quickly cooled down. This controlled thermal cycle leads to the residual mechanical stress typical of tempered glass, which makes it robust and ensures that the glass breaks into small rounded pieces.

However, tempering the glass uniformly along its surface is difficult due to a variety of factors such as the distance between rollers, the heat distribution inside the furnace, the speed at which the glass flows and cools, the orientation of the glass pane on the rollers: pressure and stress vary across the glass pane and from one pane to another, which is the cause of anisotropy effects of different intensities.

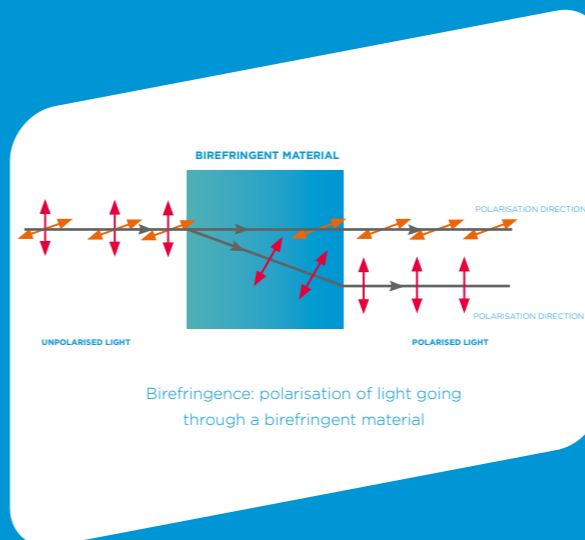
SCIENCE OF LIGHT AND BIREFRINGENCE

At the end of the 17th century, Dutch physicist Christiaan Huygens discovered that light was a wave that could propagate. More than a century later, around 1809, Etienne Louis Malus, a French scientist, introduced that light has a geometrical component and has associated “poles” which will later give the term of “polarisation”. Sir David Brewster, a British physicist, helped completing this work a few years later through his explanation of birefringence and carried fundamentals experiments about the photoelastic phenomenon that links mechanical stress in a material with its birefringence.

Birefringence is an optical phenomenon that happens with some materials such as quartz. In these materials, depending on their polarisation, a light wave path is split in two when propagating in these materials inside (an effect called double refraction).

Quartz is part of the crystals family which are strongly anisotropic materials. Birefringence also occurs in heat-treated glass but with an intensity that is much less than in the case of quartz: the double refraction is too weak to make visible doubled images.

Light will propagate at different velocities on the two slightly different paths it takes and a delay will occur between the two. When exiting the material, the optical retardation experienced on one of the paths creates an interference effect that we observe as quench marks.



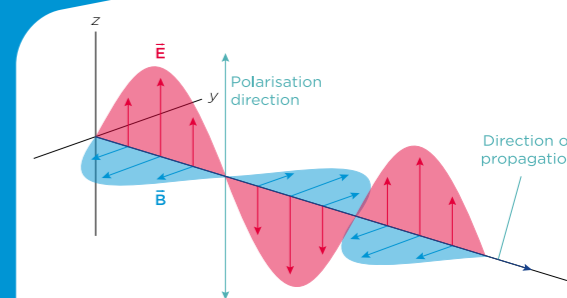
GOING FURTHER

PHYSICAL PRINCIPLES

FROM LIGHT POLARISATION TO THE OBSERVATION OF FAÇADES

Scottish physicist James Clerk Maxwell started to publish from the 1860s scientific papers on a first complete framework to explain light as a wave. Light can since then be described as an electromagnetic wave. It consists in an electric field E and a magnetic field B that can oscillate along any direction transverse to the light propagation, E and B pointing to directions that remain perpendicular to each other.

By convention, the polarisation of light is defined as the direction of the electric field E. In the case of light emitted by the sun or by most light bulbs, which actually contains many different rays of light, the direction of the electric field of each constituent is random. As no particular direction prevails, the light is therefore said to be unpolarised.



Light polarisation is defined by the direction of oscillation of the light wave's electric field

Unpolarised light can however become polarised by interacting with the molecules constituting our atmosphere (Rayleigh scattering) or after being reflected on some non-conductive (dielectric) surfaces such as glass, water or plastic.

That is the reason why quench marks are better revealed when the façade is close to a body of water (lake, sea...) or other buildings. The degree of polarisation, from unpolarised to completely polarised, is highly dependent on the sun direction and at which incident angle it hits reflective surfaces. When a polarised light goes through a diffusive medium such as textured glass or clouds, it becomes unpolarised again. That is why anisotropy effects in glass can better be seen when the sky is blue.

The angle of observation matters to reveal quench marks. The maximum visibility of these marks is obtained when observing the façade at the Brewster angle which corresponds to a certain position and distance. And as heat-treated glass changes the polarisation of light, if you wear polarised sunglasses, the marks are even more visible!

WHAT MAKE ANISOTROPY EFFECTS VISIBLE?

A MATTER OF CONDITIONS

If and to what degree anisotropy effects are visible on heat-treated glass is dependent not only on its physical properties, but also – and more importantly – on observation conditions: the environment, the weather or time of day, the building’s location, its height, surroundings or interior but also the observers themselves and their viewing angle. All these determine the shape and intensity of anisotropy effects on the façade. This complexity is the reason why it is difficult to effectively and reliably quantify anisotropy effects.



TIME OF DAY AND WEATHER

The amount of polarised light changes depending on the intensity of the sunlight and the sun elevation in the sky, and with it the visibility of anisotropy effects.



VIEWING ANGLE

Depending on how the observer is looking at the façade – straight on or at a certain angle – anisotropy effects can appear with varying intensity.



COATINGS AND GLASS COMPOSITION

When it comes to glazings with multiple tempered panes, the anisotropy effects of each glass may interact with each other, which can either intensify or minimise the effects. This also applies to coatings, the composition of which can affect the light transmission and reflection of the glass as well as the visibility of quench marks.



BUILDING HEIGHT AND LOCATION

Depending on its location and height, a building could be exposed to varying levels of sunlight intensity, which makes anisotropy more visible.



ENVIRONMENT AND BACKGROUND

If there is water, snow or another reflective (and non-metallic) surface in close proximity to the façade, the degree of light polarisation increases and, with it, the degree of anisotropy effects. The interior of the building also plays an important role: a brighter interior can outshine the anisotropic effects, whilst a darker background makes them more pronounced. This is particularly visible during the construction phase, as perception of the effects deviates significantly depending on whether the building is empty or completely furnished.



INDIVIDUAL PERCEPTION

The perception of anisotropic effects also depends on the observer himself. His body height and his distance to the building will affect the viewing angle. The use of polarised glasses will increase the intensity of the defects. Finally, the perception of the anisotropic defects is also subjective and will depend on the observer’s experience, sensitivity and personal preferences.

The perception of anisotropy effects is dependent on many factors, some of which are subjective. Depending on the viewing circumstances, the same glass can reveal contrasted patterns or appear entirely homogeneous, making it difficult to effectively and reliably quantify anisotropy effects.

OPTIMISATION OPTIONS

ON THE PATH TO SUCCESS TOGETHER

Heat-treated glass is an absolute must for modern glass façades but it unfortunately comes with anisotropy of the material. A more homogeneous, aesthetically-pleasing façade is possible if building planners, architects, designers, project owners, façade makers and engineers work closely with glass manufacturers and glass processors.

If everyone involved in the project is familiar with the parameters influencing the appearance and visibility of anisotropic effects, and the impact they have on the intensity of anisotropic effects, suitable measures can be introduced in the planning stage to minimise them.

The parameters that can be influenced to some extent – building design, glass composition or the shape and size of the individual panes – can be selected with a focus on local conditions and, if necessary, adjusted during the mock-up phase. It might also be useful to organise additional quality assurance meetings on the manufacturer’s premises and at the planned location during the planning phase.

Thanks to optimisation of production and processing, glass manufacturers and glass processors can work together to reduce anisotropic effects and improve measurability. This includes management of the heat-treatment process, use and correct operation of the anisotropy scanner, and evaluation of the acquired measurements.



DESIGN OF FAÇADE

Architects & Designers
Engineers & Façade makers...

- Risk assessment by design
- Scoring & Standards



PRODUCT OFFER

Glass Suppliers

- Low sensitivity coatings
- Easier to process products



TEMPERING SKILLS

Glass Processors

- Technical skills
- Monitoring tool (Scanner)
- Anisotropy controlled glazing



ANISOTROPY QUALITY CLASSIFICATION AND CONSISTENCY OF PRODUCTION

Glass Processors

- Agreement on quality for projects (Mock-up) and tailored anisotropy quality
- Quantification method and quality control report of production
- Reproducible objective results that fit the observed intensity of anisotropy effects on Mock-ups.

QUANTIFYING ANISOTROPY

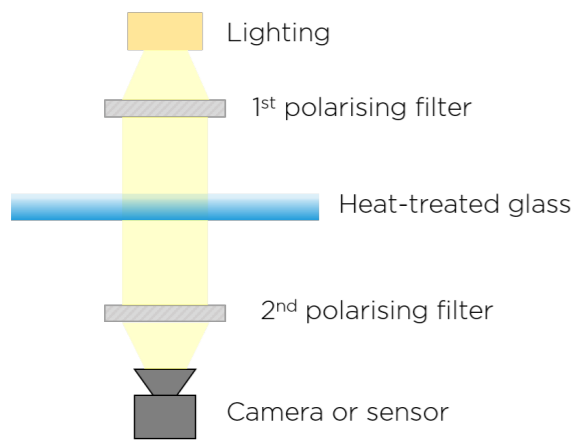
TAILORED QUALITY

To prevent unnecessary anisotropy effects in the glass façade before they occur, the degree of anisotropy in individual panes needs to be assessed.

This was once a time-consuming manual process; in recent years, more and more dedicated inspection systems have been installed on the tempering lines.

WHAT DO ANISOTROPY INSPECTION SYSTEMS MEASURE?

These inspection systems (scanners) measure, in transmission, the level of anisotropy within single panes of heat-treated glass. More precisely, they quantify the delay between the two almost undistinguishable paths that light takes in the heat-treated glass due to the material slight birefringence. This delay is called optical retardation and is measured, in nm (nanometres = billionth of meters). This measurement is performed by shining polarised light through the glass, and analysing the output light polarization with the help of cameras or sensors.



Anisotropy quantification method implemented in current commercial dedicated inspection systems

These scanners output the full glass optical retardation map and compute simpler derived criteria that can help glass processors optimizing the tempering quality.

TOWARDS A UNIVERSAL MEASUREMENT?

In the framework of a collaborative study at the standardisation level, Saint-Gobain Glass worked with other players of the market to develop a quantitative measurement method that provides meaningful results. In 2021, an ASTM standard¹ on the measurement method was published. It officialises that the industry developed a reproducible and accurate method to measure the level of anisotropy in monolithic glass. Today, many commercial scanners installed at the exit of the tempering furnaces already comply with this standard.

This was a major step towards quantifying anisotropy in a way that can be accepted by all. However, the ASTM standard purpose is only to propose a measurement method and not to provide a specification.

In 2022, a German specification document was published (DIN Spec 18919) to define quality classes, still for monolithic uncoated glass panels, based on the measurement performed by the inspection systems.

Current anisotropy inspection systems qualify monolithic - uncoated as well as coated - glass panes after heat treatment, giving information on the retardation map of the glass. The actual visibility or perception of the anisotropic effects on the façade depend not only on the level of optical delay measured by the scanner, but also on the optical properties of the measured glass. For example, a coating might decrease or enhance the visibility of anisotropic effects. Furthermore, the presence of multiple glass panes, potentially coated, can affect the actual visibility of the anisotropy of the final Insulated glazing unit (IGU) assembly.

A NEW QUALITY CRITERION FOR COATED GLASS

Saint-Gobain Glass has been working on providing the right products for the market. Thanks to its knowledge on glass coatings, a new way to uniquely characterise their effect on quench mark visibility was developed. The σ_{QM} (sigma-QM) parameter is Saint-Gobain Glass' solution to quantify the impact of coatings on the perceived anisotropy quality².

The σ_{QM} takes into account the way light interacts with the coated glass, including the interferometric effects occurring within the coating. It is computed considering the lighting conditions that most enhance the visibility of anisotropy effects (see WHAT MAKES ANISOTROPY EFFECTS VISIBLE).

The σ_{QM} is an indication of the shift between the nominal colour of a coated glass and the actual colour perceived in the presence of quench marks on the coated glass. By combining the σ_{QM} with the results of anisotropy scanners, Saint-Gobain Glass created a new quality criterion for monolithic coated glass after heat-treatment. Designed to be integrated in industrial anisotropy scanners, this "monoscore" enables processors to select the coated glass according to their full anisotropy quality right after the tempering furnace.

GOING BEYOND: VISIBILITY OF ANISOTROPY EFFECT ON FINAL PRODUCT

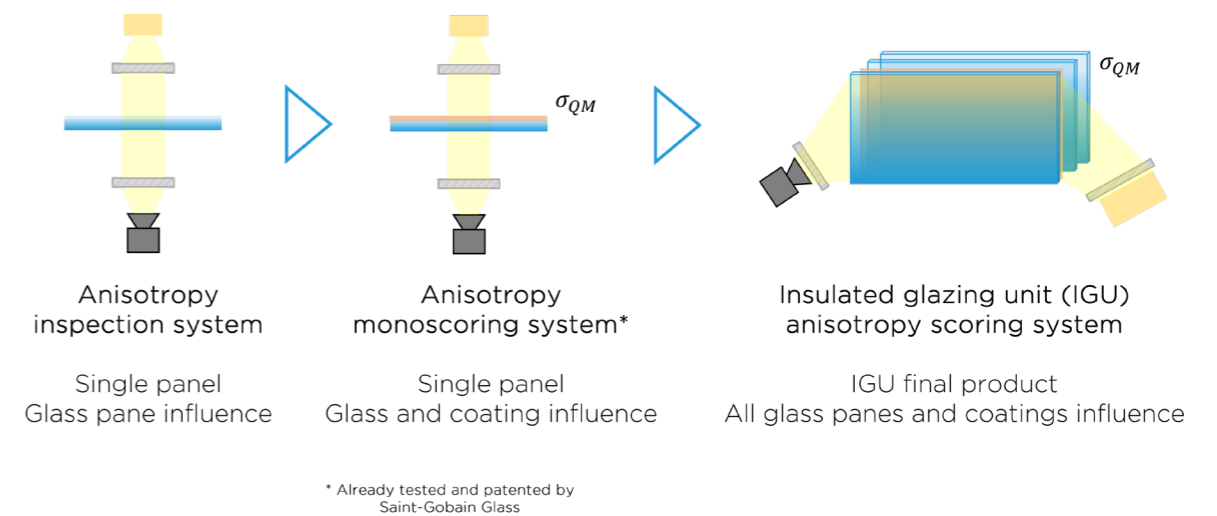
Even though the visibility of anisotropic effects in the final insulated glazing units (IGU) will depend on the anisotropy quantification of each glass pane, the actual impact of each glass remains to be determined.

In the future, inspection systems would have to grade the anisotropy quality of final products such as IGU. An "IGU anisotropy score" would predict how visible the quench marks will be once the glazing unit is installed in its target façade, whatever the IGU composition. Such a scoring system would consider all the elements of an IGU: the different glass substrates but also the applied coatings.

This would make it possible to address the uncertainty about anisotropy when purchasing an IGU for a façade project. Not only would it be possible to know in advance what the perceived quality of the glazing installed, it would also be possible to define the anisotropy quality class required for the most demanding projects.

These IGU quality classes would guarantee the beauty of the building's façade in all weathers, in all places and over time.

Perspective of the evolution of the anisotropy quantification method and inspection systems



¹ASTM C1901-21e2, Standard Test Method for Measuring Optical Retardation in Flat Architectural Glass

<https://www.astm.org/c1901-21e02.html>

²Coatings Sensitivity to the Quench Marks

<https://www.glassonweb.com/article/coatings-sensitivity-quench-marks>



TECHNICAL SECTION: TEMPERING SKILLS

A QUESTION OF TECHNOLOGY

Homogeneity is the most important factor for reducing anisotropy, both during the heating and the cooling phase. Conditions need to be consistent throughout the production line at all times, making continuous inspection and uninterrupted monitoring indispensable.

Multiple factors influence heat distribution in the tempering furnace: heat transfer, reflection and air circulation. All these parameters need to be optimally managed to ensure, for example, that the temperature of the transport rollers does not deviate from that of the heating rods.

The following aspects are to be taken into account during the tempering process to ensure the temperature remains as consistent as possible across the glass:

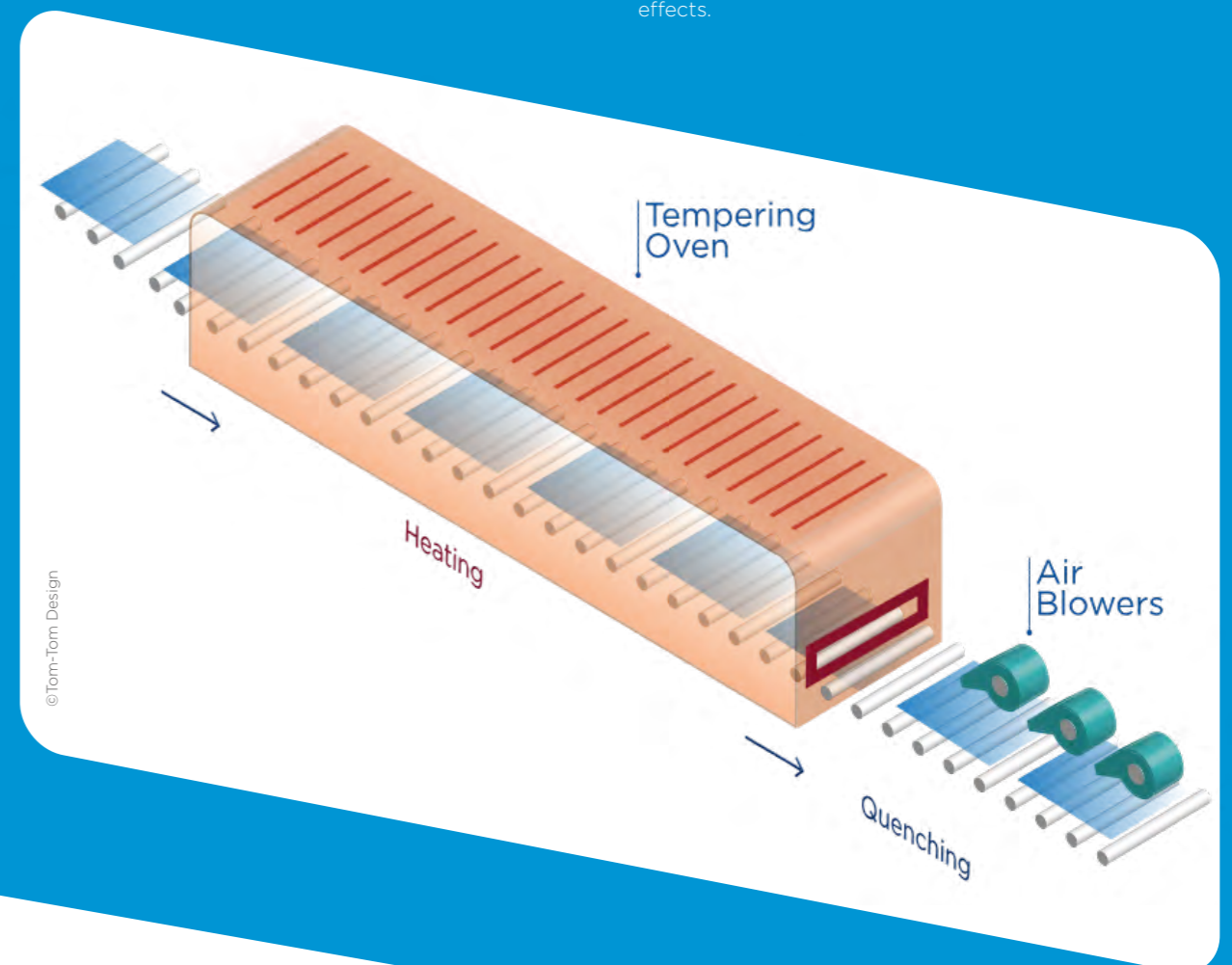
- Convection (power and time)
- Temperature of the heating elements with efficient regulation
- Time in the furnace
- Oscillation speed in the furnace

Convection blowers and transport speed are the primary elements responsible for subsequent cooling of the glass. As in the tempering furnace, consistency is also the aim here – cooling should be as homogeneous as possible across the glass. The following factors play a key role:

- Design and distribution of the blowers
- Quenching pressure and cooling
- Oscillation speed in the cooling area
- Maintenance of the rollers and blowers

Parameters need to be continuously managed, measured and, if necessary, adjusted during the heating and cooling phase to produce glass with nearly imperceptible anisotropic effects. The scanner at the end of the production line is a key element of quality control. It should be typically well-adjusted to the capability of the emissivity of the product in order to properly monitor the heating homogeneity.

Saint-Gobain Glass works closely with its customers to optimally manage the complex interplay of all the parameters associated with glass processing and to implement projects with impressive glass facades. A worldwide network of Saint-Gobain Glass support technicians (TSM) can help glass processors to improve their tempering quality. Good maintenance of the furnace is key to reduce the occurrence of anisotropy effects.

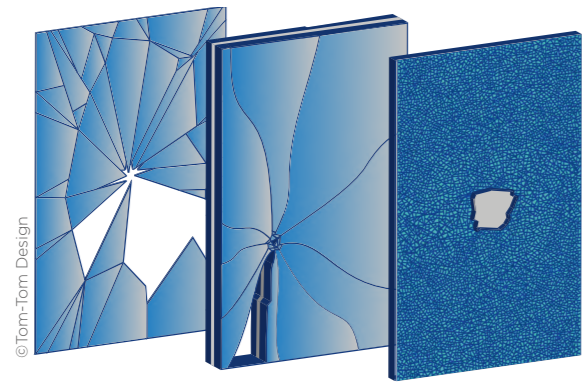


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HEAT-TREATED GLASS: A QUESTION OF SAFETY!

SOMETIMES IT JUST NEEDS TO BE MORE

Glass façades need to tick all the right boxes: in addition to looking perfect, they also need to fulfil high safety standards and be able to withstand extreme fluctuations in temperature, wind and changing weather conditions.



Float glass Laminated glass Fully tempered glass

A suitable glass must be selected to fulfil these requirements and prevent damage and injury.

Traditional flat glass offers the benefit of a flawless facade appearance but storms, hail or just the right impact could lead to breakage, resulting in sharp shards of glass.

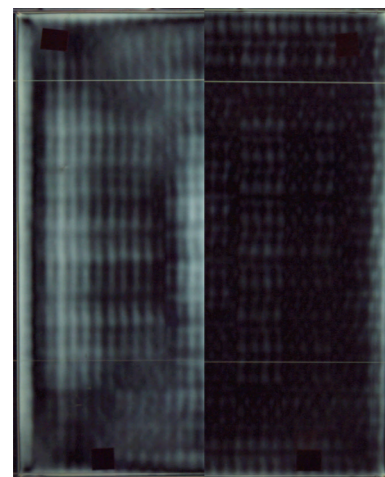
In contrast, heat-treated glass is much more durable. Its inherent residual stress makes it more stable and thus more resistant to thermal breakage and mechanical stress. If the worst happens, fully tempered glass break in small and blunt shards minimising the risk of injury. This makes them suitable for use on tall buildings, as curved or structural glazing and enameled cladding among others.

EASYPRO®

GETTING THE BEST OUT OF IT

Aesthetics and quality in architectural projects are what designers and clients demand. In this regard, the handling of coated glass from the coating deposition through the processing steps to the final product is a hot topic, with the objective to reduce defects while maintaining the highest quality of glass in a flawless and pristine state.

Saint-Gobain Glass developed therefore a unique innovation called EASYPRO®. This temporary layer helps not only to protect coated glass from scratches and damage but also proves to be an ally in the reduction of visual defects, by easing the processing of heat-treated glass.



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WITHOUT EASYPRO® WITH EASYPRO®

EASYPRO® is deposited on to-be-tempered coated glass and delivers effective protection against mechanical damage as well as ageing from deposition of the coating until tempering. During tempering, EASYPRO® simply burns off without leaving any residue inside or outside the furnace and without any negative impact on the environment or personal health and safety.

EASYPRO® also contributes to the improvement of the quality of glass after tempering. It helps to get a better distribution of heat across the glass. This simplifies the tempering process of coated glass, which reflect furnace heat. At the end of the heating phase, the coated glass is thermally more homogeneous, which helps minimizing anisotropy.

UNCOMPROMISING

If productivity falls as quality standards increase – for example, because more time is required to process glass fitting with the required level of quality – EASYPRO® can help not to have to choose between the quality of the tempered glass and the productivity.

EASYPRO® helps to reduce tempering cycle times up to 20% (depending on tempering furnace type) while contributing in keeping high quality of tempered product for all ambitious projects.



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