Technical Services Bulletin ATB – 106 *STRAIN PATTERN*

Strain pattern or quench marks are an inherent property of heat – treated flat glass products. The process of air quenching for fully tempered or heat strengtned glass creates a small density change in the glass surface relative to the quench nozzle location. In the presence of polarized light the locations of quench air blast will often appear as iridescent or dark areas. The confirmed observation of this optical phenomenon is a positive indicator the glass has been thermally treated and is not considered a defect.

The appearance of strain pattern is linked to polarization of light or the imparted property of bi refringence. During the process of heat treating glass the small areas impinged by high pressure quench air undergoes a slight density change. The resulting localized change in refractive index creates an out of phase spacing which the observer see's as dark spots or iridescent areas in the glass.

The key to determine strain pattern versus other defects is the viewing angle. In normal viewing conditions of approximately ninety degrees perpendicular to the plane of the glass the phenomena is not visible. As the observers angle of view decreases the pattern or iridescence will become visible and more intense depending on the critical angle of light incident to the glass. (See figure 1) Since the properties of the glass are only partially modified in localized areas the result visually is a series of light and dark areas.

Polarized light is to some degree always present. The daily and seasonal solar cycles constantly changes the incident angle of the light source and lends a transient nature to the appearance of strain pattern. The reflection by objects all around us influences the polarization of light as various surfaces absorb, transmit or reflect visible light waves. Portions of light reflected close to the ideal or Brewster's Angle[1] will be polarized linearly with the light wave oscillating in single directions and out of phase. Reflective areas not normally thought of but which are strong polarizer's is blue sky, especially northern or horizonal sky. Snow covered ground, undisturbed water features or even large areas of polished floor tiles that can produce reflected polarized light. Additionally other factors influencing visibility are multi light assemblies, reflective glass coatings, lighting differential and the acuity of the observer. The stacking of layers of partial polarizer's or re reflecting polarized light from thin film reflective coatings magnifies the existing conditions and in some instances may exacerbate the condition due to crossed polarizer's. Additionally during the construction phase low levels of interior light cause the pattern to appear more intense than what will be observable once construction is completed. The higher level of generated and reflected interior light will tend to cancel part of the polarization and reduce the phenomena.

The glass industry recognizes the inherent property of bi refringence in heat treated glass and addresses the issue:

ASTM C 1048, Standard Specification for Heat Treated Flat Glass, Kind HS, Kind FT, Coated and Uncoated.
"Section 7.5 Strain Pattern – In heat strengthened and fully tempered glass, a strain pattern, which is not normally visible, may become visible under certain lighting conditions. It is characteristic of these kinds of glasses and should not be mistaken as discoloration or non uniform tint or color."

The inevitable appearance of strain pattern is often compared to other existing glazing or buildings. One should consider the observation is based on the geometry of light source, reflected polarized light, the incident angle of the glazing and the angle of view of the observer. When comparing glazing substrate, heat treatment and plane of the glazing must be identical to be meaningful. The comparative product may display a stronger bi refringence, less bi refringence or display a different pattern of iridescence between furnaces and from different fabricators. Since the phenomenon is an effect of ambient site conditions, the heat treating process, glass or coating selection remedial action is difficult to achieve. The appearance of this inherent property is not a defect or cause for rejection of heat treated glass.

[1] Brewster's Angle When considering the incidence of non-polarized light on a flat insulating surface, there is a unique angle at which the reflected light waves are all polarized into a single plane. This angle is commonly referred to as Brewster's angle, and can be easily calculated utilizing the following equation for a beam of light traveling through air:

$$n = \sin(\theta_i)/\sin(\theta_r) = \sin(\theta_i)/\sin(\theta_{90-i}) = \tan(\theta_i)$$

Where n is the refractive index of the medium from which the light is reflected, θ (i) is the angle of incidence, and θ(r) is the angle of refraction. By examining the equation, it becomes obvious that the refractive index of an unknown specimen can be determined by the Brewster angle.

The principle behind Brewster's angle is illustrated in Figure 1 for a single ray of light reflecting from the flat surface of a transparent medium having a higher refractive index than air. The incident ray is drawn with only two electric vector vibration planes, but is intended to represent light having vibrations in all planes perpendicular to the direction of propagation. When the beam arrives on the surface at a critical angle (Brewster's angle; represented by the variable θ in Figure 1), the polarization degree of the reflected beam is 100 percent, with the orientation of the electric vectors lying perpendicular to the plane of incidence and parallel to the reflecting surface. The incidence plane is defined by the incident, refracted, and reflected waves. The refracted ray is oriented at a 90-degree angle from the reflected ray and is only partially polarized.

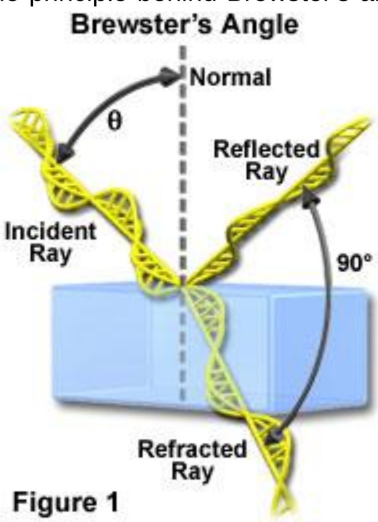

Figure 1

For water (refractive index of 1.333), glass (refractive index of 1.515), and diamond (refractive index of 2.417), the critical (Brewster) angles are 53, 57, and 67.5 degrees, respectively. Light reflected from a highway surface at the Brewster angle often produces annoying and distracting **glare**, which can be demonstrated quite easily by viewing the distant part of a highway or the surface of a swimming pool on a hot, sunny day.

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