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RESEARCH ARTICLE

The effect of optical anisotropies on building glass façades and its measurement methods

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Abstract
Commonly, in the evaluation of the optical appearance of glass panes in building envelopes, anisotropies are a reason for a dispute between the architect or client and the façade manufacturer. Sometimes each party has a different perception, how strong the anisotropies are and what is permissible.
This paper discusses in the first part the formation of the anisotropies and their natural sources. It is shown that the appearance of this phenomenon is dependent on the environmental conditions of the building site as well as the glass quality. If the application of thermally tempered glass cannot be avoided, the quality assurance of the production process has to be carefully planned.
Furthermore a method for the quantitative measurement of anisotropies is proposed and prescribed in detail. This method can assist in the quality assurance process. Measurements are showing that probably the best tempered glass offers slight anisotropies and that under unfavorable conditions these anisotropies can become evident.

1. Introduction

Today façades are individual building envelopes with larger parts of glass. It is spent much effort on the aesthetic design and the high-quality-look of the whole project to fulfill the clients expectations. But sometimes, if one looks at these glazings colored stripes and spots, which are known as anisotropies in a façade context, can be observed (Figures 1 and 2). From an architectural point of view these patterns are unaesthetic and disruptive.

In general, the anisotropy can be defined as a characteristic of a material, that has directionally dependent properties (e.g. tensile strength, conductivity, wave speed, refractive index). Here, the anisotropy effect results from the presence

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Nomenclature

α, β	angle of incident and refracted beam
α_B	Brewster's angle
δ	relative phase shift
η, η_{max}	relative degree of polarization, maximum degree of polarization
γ, ψ, θ	angles in the hemisphere according to Figure 7
λ	wavelength
σ_1,σ_2	principle stress
C	stress-optical constant
d	thickness
E	error value
I_i, I_r	intensity of incident and reflected beam
n	refraction index
R	reflection coefficient
s	absolute phase shift

of polarized light in the natural environment, the birefringent property (anisotropy of the refractive index) of the glass (photoelasticity) and mechanical stresses in the glass due to the tempering process.

Normally, the effect of this phenomenon is stronger on days with a clear blue sky and varies with the angle of incidence as well as with the relative position of the sun to the glazing, due to the high degree of polarization of the light under these circumstances (see Section 4.2). But it seems that not only the blue sky forces the anisotropies, but also the presence of a smooth water surface, wet streets, polished granite flooring or other shiny non-metallic objects abets the appearance, because these surfaces emit or rather reflect polarized light too (see Section 4.1). The reflection of light by metallic objects does not intensify the degree of polarization since the underlying physical process is different (emitters are electrons not Hertzian dipoles). Black background behind the glass makes the effect more visible than light ones. Thicker glasses or laminates of two or more panes show a stronger effect than thinner glasses, because the path of the light through the glass is longer compared to the thin ones. Otherwise, the reflections of bright objects and buildings are stronger than the visible anisotropies, so that it will not be noticed by the observer anymore. Furthermore only tempered glass is affected, due to the imposed mechanical stresses. In most cases nothing of the prescribed effects are noticed at the manufacturing.

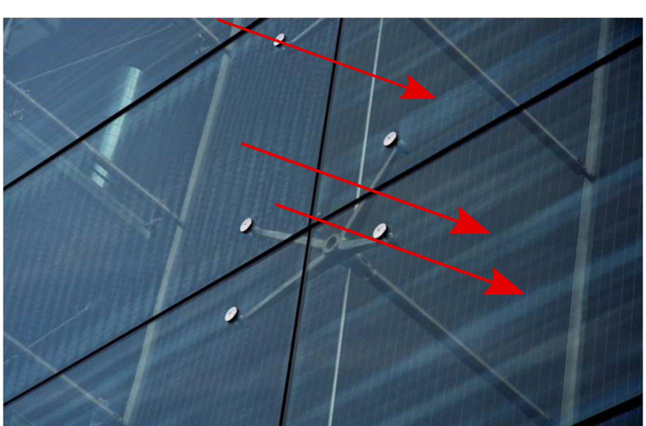

Figure 1 Visible anisotropies at a façade glazing; horizontal stripes.

Currently, there is no technical solution that offers the possibility to quantify these optical anisotropies over the whole glass pane for comparison and quality assurance purpose. Sometimes architects are checking the quality of the glass with a special polarization filter in front of their eyes after the glass processing. However, this method leads to subjective results, it is not reproducible and also poorly documentable.

In this paper, we will discuss the corresponding physical effects which lead to these optical anisotropies. Furthermore a proposal for measuring the anisotropies without the named disadvantages is given, which enables us to quantify the anisotropies and compare mock-ups and batches of glass before they are mounted on the façade.

2. Thermal tempering

With the thermal tempering process the mechanical strength of glass is increased. Normally this is done by heating a glass pane above the transition temperature. After that the panes are rapidly cooled down to ambient temperature. This treatment generates a residual stress profile across the thickness with compression stresses at the surface of the glass.

To receive a good quality glass, concerning the optical appearance and strength, an optimized and monitored cooling process (the quench) is indispensable.

Today, almost all quenches consist of an array of rollers and cooling nozzles. The rollers are wrapped with special heat resistant fabric stripes. Through the thousands of cooling nozzles the hot glass surface is cooled by impinging air jets while the glass lies on the rollers and oscillates. The large amount of cooling nozzles and the oscillation of the pane shall guarantee a uniform heat transfer and therefore a homogeneous residual stress profile in the whole glass pane, independent of a direction.

But practically, at any time the glass is in contact with the rollers somewhere at the surface. Furthermore the cooling is influenced by the flow of the air. Monnoyer and Lochegnies (2008) simulated the flow field of the quenching process. They showed that the air from the nozzles at the middle of the pane crosses the jets at the border area. Thus, the heat transfer is disturbed at the contact points as