Detecting white haze on tempered glasses

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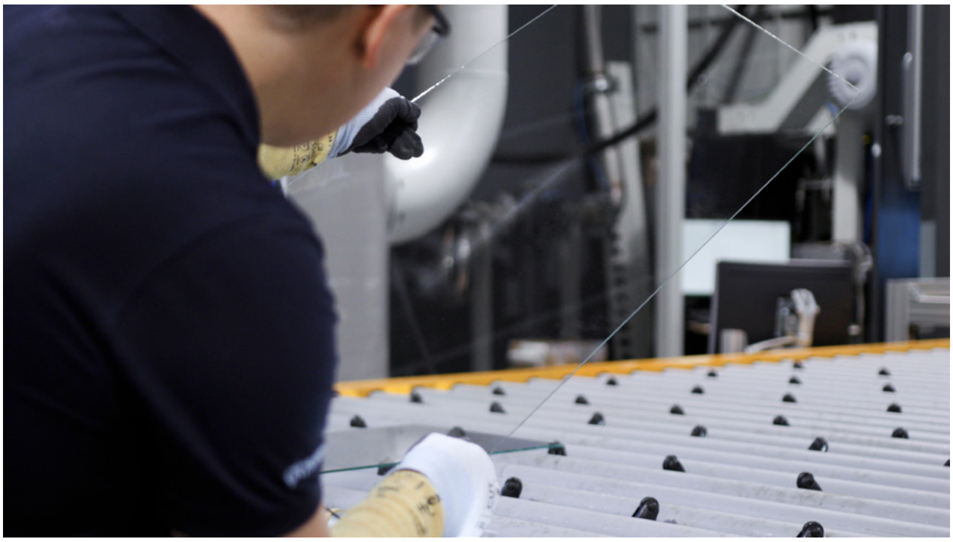

Figure 1

1. Abstract (Glaston & Softsolution)

White haze has been a hot topic in the glass industry for decades. Correcting white haze related issues can be a bit like hunting a ghost – as there's a huge amount of different items that can affect the creation of white haze in the tempering process. At the same time, detecting white haze has been based completely on subjective manual inspection.

2. How do we see white haze on glass?

White haze can be described as very small scratches, which appear on the glass surface as vague, foggy areas or repetitive stripes. The phenomenon is also called "ghosting" (Fig.1). One of the most common signs of white haze is a long blemish in the center of the glass. The effect can also appear near the edges, on the corners – or even all over the glass. There are many reasons why white haze can occur, and all of them can be solved by eliminating the root cause. A systematic approach is key here.

What causes white haze

Pre-processing

In our experience, up to 80% of white haze issues are caused during the processes prior to tempering. Only around 20% appear as a result of tempering itself.
Most white haze is nothing more than glass dust generated by the edge grinding process. The dust should be washed off the pre-processed glass in the washing machine. However, if the water wasn't cleaned properly beforehand and starts recirculating, it creates a fine dust layer on the glass. During tempering, this layer fuses onto the glass and appears as white haze.
The solution is to wash and rinse the water tanks of the glass washer often and properly – if necessary, more than once per day.

Know the tin side

Another measure that helps reduce the severity of possible white haze before tempering is to check which side of the glass has the tin side. When float glass is manufactured, one of its sides touches the molten tin, which then leaves an invisible tin coating on the glass. The other side is known as the air side. Checking which side is which is easy with a short-wave ultraviolet light, which reveals the slight fluorescence the tin coating side obtains.
Keep in mind that white haze appears more severely on the air side. So, run the glass tin side against the rollers whenever possible.

Mechanical issues

The most common reason for white haze in the tempering process itself is residue on the furnace rollers. This residue then causes tiny scratches on the glass surface. If this is the case, examine the roller surfaces. Are they rough, cracked or brittle? Are there any solid particles on the surfaces? If so, take corrective action accordingly.
It's important to ensure there is no chance of dust flying into the furnace. General cleanliness of the production environment is key. In addition, take care to inspect the insulation. Furnace doors should be in perfect operating condition to prevent any particles from entering the machine.
The leveling of the rollers is also important. If they are not properly adjusted, white haze can be caused by mechanical pressure that is too strong between the glass and the rollers.
Last but not least, check out the drive system. Is the drive speed consistent? Are the belts in good condition? Make sure the roller bearing works well.

Process parameters

If the root cause is in the process parameters, you will notice that the defect is not always repeated. It may be only a certain glass thickness or type that ends up with white haze marks.
If you're dealing with non-optimized tempering parameters, you should be able to fix the issue by adjusting the settings to run the glass as flat as possible. One way of doing this is by decreasing the temperature of the bottom section and/or increasing the top convection. Note! Excessive top convection creates a different glass quality issue.
White haze in general has been a subjective topic, that often requires special lighting conditions and observation setups to really become visible. Even "visible white haze" can be missed if glass is just quickly viewed at the unloading table. In order to start to reliably detecting white haze, three main challenges needed to be solved:

- How to produce a reliable image of white haze
- How to detect white haze from the images
- How to evaluate the detected white hazes

Next, let's review how these issues were tackled.

3. White haze scanner hardware development

Hardware Development

To achieve a stable solution of an industrial image processing application, an essential factor related to the hardware used is the illumination.
As with our unique LineScanner, for which we have developed a parallel light technology, this topic plays a very important role.
For this reason, we first addressed this issue - i.e. selection/development of an ideal illumination.
In the first step, we tried to make the very fine scratches/surface changes of the white haze effect visible with high-resolution imaging sensors (400dpi) using extremely short-wave light.
At this high resolution (equivalent to 250Mpixels per m² of inspected area), strong white haze effects were visible in reflected light mode, but the real breakthrough was only achieved by using a solution similar to dark field illumination, with the light source positioned laterally. It was important to ensure that all light passing through the glass without interference was 100% absorbed and that there were no disturbing light scattering effects.
It was equally important to ensure that the light reflected from the two glass surfaces due to the optical law (angle of entry equals angle of exit) does not fall on the imaging sensor and thus overdrive (overexpose) the already low reflective stray light caused by the white haze effect.
For this purpose, a special rod light array (gradient lenses or SELFOC® gradient optics - Wikipedia) was used, which ensures that only that light penetrates to the imaging sensor, which has an emission angle of 90° (relative to the glass surface (normal) - the remaining light is optically absorbed (Fig. 2).

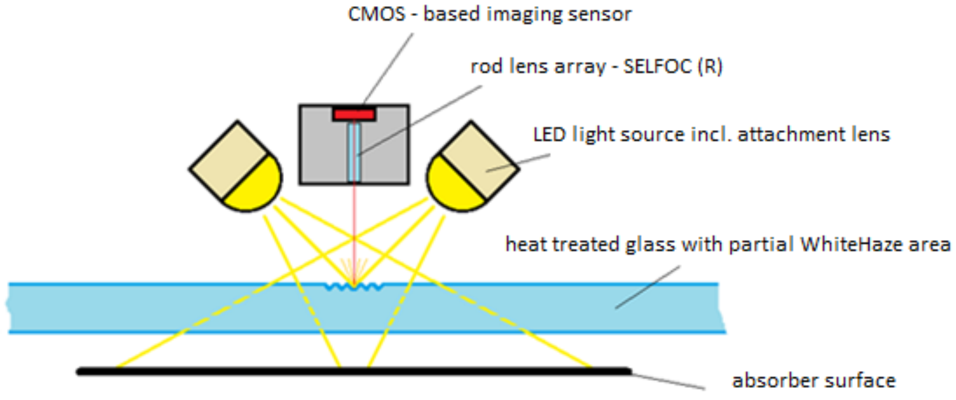

Figure 2

Figure 3

Hardware - Background

Usually, the inspection of flat glass (transparent objects) relies on the transmitted light method. The basic arrangement is to place a light source on one side and an optical sensor/camera on the other side of the glass pane.
The emitted light normally passes almost unhindered through the material to be examined and the intensity is measured. Disturbances in the glass pane lead to an absorption or scattering of the emitted light and thus a reduction of the measured light quantity occurs in this area and a more or less strong darkening occurs.
Due to its very low scattering, the white haze effect leads to a too weak darkening (especially with mild or medium effects), so it was decided to use a special kind of dark field illumination.

Here, the light source and the imaging sensor are located on the same side of the glass pane. With an optically perfect glass pane, approx. 97% of the emitted light passes through. "through" and about 3% is reflected according to the optical law. The important thing with the optical arrangement is that none of it hits the imaging sensor.
However, if the pane has an optical defect (which, as in the case of white haze, can also be very small), it leads to a scattering of the incoming light at the surface and part of the thus diffusely scattered light hits the imaging sensor and causes the white haze area (as well as other disturbances such as the edge of the glass or, however, holes) to leave a bright area.
A measurement of the glass geometry (also applies to cutouts, drill holes, etc.) is therefore also permissible.
Based on the presented approach and experiments, we were able to develop an overall hardware solution for the best possible image acquisition.
By using a modular design, we can construct hardware of almost any width/height. Thereby a constant resolution is given over the entire acquired scan area.

4. Detecting and evaluating white haze

After we were able to have reliable image of white haze if it is present on glass, the next big question is that how should white haze be detected an evaluated.
Detecting white haze(s) from glass is still difficult with traditional image processing methods, as there are lots of marks (e.g. kevlar marks) that can be easily mistaken with white haze. To overcome this, we decided to use a deep-learning neural network to detect and classify white hazes. The used neural network has been taught with data from different machines and different kinds of white hazes so that it is able to reliably detect them.
In order to overcome the subjective and somewhat vague nature of white haze, we realized that the only way forward is to work towards a common glass industry standard for white haze. For this we performed a practical study with industry experts and glass processors on actual glass samples. In the study the industry participants viewed the sample glasses and defined

1. Where they are able to find haze from each glass
2. How severe are the hazes they have been able to find, especially considering that would it be an issue for using the glass as an end product in different use cases (Fig. 4)

From the collected data we defined guidelines as to how to evaluate the glasses. The result is that we divide white hazes into three categories as below:
Mild is a barely visible effect not normally considered a problem by the industry. This kind of haze is often only visible with external light source with closer inspection.
Medium indicates slightly visible haze that might require external light to be seen. Such glass can be undesirable, especially for quality-oriented customers. But also for many uses cases, such glass is perfectly fine to be used as an end product.
Strong indicates visible haze that even a non-trained eye can spot from the glass. In many cases, tempered glass with such defects is considered unacceptable to the end customer.
For categorizing the hazes into the three categories, the neural network is using the same logic that was created in the original test with glass industry experts. This approach ensures that detection is always objective, and that it reflects common understanding of industry experts, rather than just the opinion of one individual or one party.

5. Future outlooks & conclusion

For the first time, we have a solution to actually enable objective discussion around white haze. Our approach from the beginning has been that we want to move forward with white haze detection together with glass processors and other industry experts, so that the detection model reflects the views of the glass industry. Now that the first version is out, how we see it, is that we have now taken a first significant step towards a common glass industry white haze standard (Fig. 5).
As we move forward, we invite glass processors and industry experts to join the development with us. Participants in the development have the possibility to affect which direction the model will be developed. This could for example mean adding more categories that are used in categorizing white hazes. As the amount of contributors to the model development grows, we are looking to ensure that the latest detection algorithm represents a common understanding of what kind of white haze is seen as an issue among glass processors.

Figure 4

Figure 5