Stress Whitening in Polypropylene Copolymers: Causes, Detection and Prevention

By: Chris Miller, Research Scientist, Americhem

Deciding upon and creating ideal coloration is an important part of any product design challenge. The challenge does not end there—steps frequently need to be taken to ensure that color will not become compromised over time as a result of environmental factors.

When dealing with certain polymeric materials, such as polypropylene (PP), one type of discoloration that can occur is stress whitening. Typically caused by impact, deformation or other physical tension on the material, stress whitening is an aesthetic issue that is never ideal. The good news is that there are ways to counteract it through added precautions and testing during processing, material selection and product design. With a bit of knowledge about the manufacture of PP, light interaction and causes of stress whitening, you stand a better chance of counteracting this condition before it ever occurs.

What Is Stress Whitening?

To prevent stress whitening, you must first understand how it works. As noted previously, stress whitening starts when stress is created by impact or tension upon a polymeric surface. This stress leads to the creation of microcrazes and/or microvoids, which are essentially the microscopic beginnings of cracks that result when stresses overcome the forces bonding particles together. Unlike surface cracks, you cannot feel microcrazes or microvoids, but you can see them. This is because these tiny aberrations reflect light slightly differently than the surfaces around them, which in turn gives them different coloration as perceived by the human eye.

How exactly does this work, and why does it happen in polypropylene? First, realize that there are various ways to compound a polymer, and PP is not always the same. There is basic PP homopolymer, which typically does not exhibit stress whitening, but it is very stiff and has limited impact resistance, making it brittle at times. PP copolymers have a better balance between impact and stiffness due to the addition of elastomers such as ethylene propylene rubber (EPR or EPDM). While this addresses the physical constraints of the PP homopolymer, it can create a new problem: stress whitening. PP copolymers are much more susceptible to stress whitening.

With polymers, property balance is always a challenge, and often, tweaking one aspect of a polymer can influence another property. In the case of polypropylene, elastomer particles that are added for increased flexibility and impact strength create the conditions for stress whitening. When a piece of PP material is impacted or deformed, microcrazes and microvoids tend to form where elastomer particles and the rest of the PP matrix interface with one another. The resulting change in the refractive index (RI) of the materials causes light scattering in the stressed areas of the polymer. The light scattering causes the perceptible color change, or whitened appearance, at the surface of the part.

Refractive index is a measurement used to describe the bending of light through a medium, and values typically range from 1 to 5 on the RI scale. Values correspond to how quickly light travels through a material compared to how fast light travels in a vacuum, where the speed of light in a vacuum is equal to 1. An RI value of 1.5, for instance, corresponds to light traveling 1.5 times more slowly than the speed of light in a vacuum. Differences in RI values can result in light scattering, or the deflection of visible light rays, which in turn affects human perceptions of color.

Since our perceptions of color are dependent on certain wavelengths of light being reflected off a surface into our eyes, when aberrations—such as microcrazes, microvoids or cracks—start to form, they can change the RI of a material, and in turn, they can scatter reflected light in a way that makes it appear as though there is a color discrepancy around the site. The result is whitening or “blushing” around an area: in essence, stress whitening.

Stress whitening does not necessarily show up immediately after an impact or tension is applied to a material; in fact, it can take days to fully appear. While results may not be immediate, testing has shown that PP tends to be 95 percent stable 24 hours after impact. Minimal whitening is likely to occur after that period, but it is important to remember this time span when deciding how to address stress whitening problems.
How Can We Test for Stress Whitening?

In order to find out what sort of changes in material, design and processing of PP copolymers result in the least stress whitening, testing must first take place to determine the success of tweaking independent variables. There are a variety of ways to test for stress whitening beyond simply looking at a piece of material, but there is no “go-to” test method that is clearly accepted in the industry.

Impact Testing

This method revolves around comparing the color of an area of material before and after an impact, looking for differences. Color is measured in the same area before and within a specific time frame after an impact, and an equation is used to determine the amount of change in the color: $\Delta L = L_{\text{elapsed}} - L_{\text{initial}}$

$L$ corresponds to lightness, or “whiteness” in this case.

Grayscale Testing

Similar to impact testing, this method measures differences in grayness levels by using imaging software.

Blush Testing

Impact testing is conducted using a drop dart to create a white ring on the surface of a polymeric part. One of two methods is then used to calculate the amount of blushing that occurs as a result of the impact: blush factor and blush index. Blush factor is calculated by multiplying $\Delta L$ by the blush diameter, and blush index is calculated by dividing the diameter of a created whitened ring by the diameter of the dart used to create the impact.

Bending Testing

This test takes an optical measurement of light transmission during the bending of a tensile bar or flex modulus bar. The higher the light transmission, the less microcracking, and therefore the less stress whitening that occurs. Conversely, the lower the light transmission, the more cracking that takes place, causing a higher degree of stress whitening to occur.
What Affects Stress Whitening?
Testing has shown that several factors can affect a material’s propensity to display stress whitening. These factors are related to material choice, product design and processing.

Masterbatch Formulation
When holding constant the PP copolymer type used and testing within the same color space, tweaking masterbatch formulation as an independent variable can lead to substantial differences in material stress whitening propensity. Changes to the masterbatch might include use of different pigment types, particle sizes or pigment levels—all result in stress whitening potential variance. (CHART 1)

Copolymer Resin Choice
When masterbatch formulations are held constant and the same color space is utilized, we find that differences in PP copolymer resin choice can also lead to variance in stress whitening potential. Even different PP copolymers specified for use in the construction of the same part can yield large differences in stress whitening. (CHART 2)
Stress Whitening in Polypropylene Copolymers:
Causes, Detection and Prevention

Variance of Resin and Masterbatch
Testing has shown that there is no one ideal solution when attempting to counteract stress whitening; different combinations of copolymer resin and the masterbatch result in notable variance. (CHART 3)

Manufactured Part Thickness
The thickness of parts being produced can also factor into stress whitening potential. The chart below shows a thinner part has worse stress whitening compared to a thicker part using the same PP copolymer and color masterbatch. Our experimentation has shown that as thickness decreases, more pigment will be needed to minimize the visible stress whitening. (CHART 4)

Nucleation in Large Parts
Nucleating agents and certain pigments can affect in-mold shrinkage during the injection molding process. This shrinkage may require more pack-out to fill the mold. The result can be a tendency for materials to stick to the mold, which requires more ejection force to be exerted on the part to free it from the mold. This added ejection force can be enough to cause stress whitening, especially in the area where the ejector pins come in contact with the part.
How Can Stress Whitening Be Avoided?
The key to avoiding stress whitening lies in doing comprehensive testing regarding the color masterbatch, PP copolymer and molding process. Does testing show that a certain masterbatch formulation is causing the most stress whitening? Does resin choice seem to be the culprit? Consider the part’s design and processing, as part thickness or significant force during processing has significant effects on stress whitening potential. Whatever the case may be, testing is crucial to isolate material variables making a product most prone to stress whitening.

There are many factors to consider when developing a product with desired performance properties and proper resistance to stress whitening. Color masterbatch formulation, resin selection, part thickness and processing conditions should all be considered when addressing stress whitening. Achieving balance between material design, part design and processing needs will provide the best defense against stress whitening. All of these factors should be understood in order to provide the most robust solution to prevent stress whitening. (CHART 5)

About Americhem
Americhem is a global organization that delivers custom color and additive solutions for customers seeking superior performance and batch-to-batch consistency for their polymer products. The company specializes in color and additive masterbatches, and single pigment dispersions, all backed by complete technical support that ensures quality, reliability and value. Americhem operates seven manufacturing plants and also maintains a representative sales office in Luxembourg and Monterrey, Mexico. Central Research & Development facilities and headquarters are located in Cuyahoga Falls, Ohio. For more information, visit Americhem.com or call 800.228.3476.