Light Stability of Plastics

- Phil Jacoby

When summer rolls around, most of us like to spend more time out-of-doors, and this often means increasing our exposure to the damaging rays of the sun. We know that exposure to the UV radiation can cause our skin to burn and prematurely age, and can also increase our risk of developing skin cancer. Many plastics are also adversely affected by exposure to the sun, resulting in color changes and loss of physical properties. We can protect our skin by shielding it from the sun's rays, but how do we insure that plastic articles maintain their appearance and properties over a reasonable lifetime?

In order to answer this question, it is first necessary to understand how the sun's rays act to cause degradation in plastics. For the purpose of this discussion we will consider what occurs in polyolefin-based materials, such as polypropylene and polyethylene. When a polyolefin part is exposed to the sun, the ultraviolet (UV) photons, which contain the most energy, can be absorbed by the polymer chain causing the carbon-hydrogen bond to break. This leaves the carbon atom on the chain with an unpaired electron and also releases a hydrogen atom with an unpaired electron. These two species are referred to as free radicals, and they are very unstable. These free radicals can go on to attack other polymer molecules producing even more free radicals, or they can react with oxygen in the air to produce peroxides and hydroperoxides, which are also unstable. In the case of polypropylene, a polymer chain containing a free radical is likely to split into two smaller chains in a process known as chain scission. This reduction in molecular weight eventually causes the part to become brittle. In polyethylene chain scission can also occur as well as another process known as branching where two polymer chains become linked together. This branching leads to crosslinking of the chains, which can also lead to embrittlement. The visual effects that often accompany this UV degradation include color changes in the part, loss of surface gloss, and surface chaulking.

In order to minimize this degradation and extend the lifetime of the part, two approaches can be used. The first is to incorporate additives into the part that screen out or block the UV radiation, much like the sunscreens that we use on our skin. One class of screeners are opaque pigments such as titanium dioxide (TiO_2) and carbon black. Carbon black is particularly effective in absorbing UV and visible light, and can be used at levels as low as 1-2.5 % depending on the required lifetime and exposure conditions. If one needs to produce a part that is not going to be white or black, there are certain UV screening compounds that primarily absorb only in the UV portion of the spectrum, and are relatively transparent in the visible region. Examples of these include the benzotriazoles, such as BLS 1328, or the benzophenones, such as BLS 531. In packaging applications these latter additives can be used to prevent the UV degradation of food products such as milk that are stored in clear or translucent plastic bottles under fluorescent lighting in supermarket display cases.

The other way of stabilizing plastics against UV degradation is to incorporate additives that act as free radical scavengers. These are compounds that neutralize the free radicals which lead to the polymer degradation. The most common of these are the hindered amine light stabilizers (HALS). There are many different types of HALS, which differ somewhat in their chemical structure and molecular weight. The higher molecular weight HALS, such as BLS 1944, are often used in films and fibers since the high surface-to-volume ratio can lead to rapid volatilization of the lower molecular weight HALS. In thick parts, such as auto bumpers, a combination of low (e.g. BLS 1770) and high molecular weight HALS is often used, since the smaller molecules will migrate more rapidly to the surface where they exert their effect, leaving a reservoir of the larger molecules to provide for longer term stability. The choice of which HALS to use is important since it can also interact with other additives in the formulation.

Another benefit of HALS additives is that they can also stabilize the part against thermal-oxidative degradation caused by prolonged exposure to elevated temperatures, even in the absence of light. The HALS are particularly effective for long term exposure to temperatures up to 120 ^{o}C, and they can even replace the common long term heat aging stabilizers, such as the thioester compounds (e.g. DSTDP). One should not, however, use HALS and thioesters together in the same formulation, since they are antagonistic towards one another. HALS are also used in applications requiring radiation sterilization such as syringes. Here the radiation treatment produces numerous free radicals which can lead to the same degradation as that caused by UV exposure.

From this brief discussion you can see that protecting a plastic part outdoors is a lot more complicated than wearing a big hat and some sunscreen to protect your skin. The choice of the proper UV stabilizer/screener depends on many factors including the geometry and color of the part, the desired end-use lifetime, and the cost. If you would like more information about the UV stability of plastics, please feel free to contact me at pjacoby@mayzo, or at (770) 449-9066, ext. 14.