Dual-Purpose ‘Laser Additives’ Drive Marking and Welding of Polymers

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Dual-purpose laser additives blended into polymers during primary processing allow for marking and transmission welding of clear and opaque polymers. Novel chemical additives, including those that are FDA-/medical-compliant, achieve high-strength hermetic seal weld joints and indelible opaque marking contrast. Laser marking and laser welding processes are noncontact, easy to control and eco-friendly. Designed for affordable, high-speed lasers and equipment, marking and welding of polymers meet the challenges of today’s complex applications.

Product applications
Clear, semi-transparent and opaque colored polymers, including nyons, polyethylene terephthalate (PET), polycarbonates, polyolefins, polyvinyl chloride (PVC), styrenics and thermoplastic elastomers (TPUs) and thermoplastic polyurethanes (TPEs), are uniquely formulated using non-heavy metal, FDA-/European Food Safety Authority (EFSA)-approved additives to achieve high-contrast marking quality, including laser welded products (Figure 1). Polymer clarity, spectral transmission and base physical properties are not affected. Noncontact digital laser marking replaces expensive adhesive labels and ink-chemical printing processes. The result is a cost-effective, environmentally friendly and superior aesthetic appeal.

Laser marking surface reaction mechanisms
The advancements achieved in formulating laser chemical additives for use with near-infrared (NIR) lasers (1060-1080nm wavelength) include their compatibility with ytterbium fiber, vanadate and Nd:YAG lasers. Most polymers do not possess NIR absorption properties without chemical additives. Polymers that can be marked by lasers are those that absorb laser light and convert it from light energy to thermal energy. Additives, fillers, pigments and dyes are used to enhance the absorption of laser energy for localized color changes. Vastly different formulation chemistries and laser optics/setup parameters are configured depending upon the desired marking contrast and functionality.

Two common surface reaction mechanisms are shown in Figure 1. First, thermal chemical “carbonization” or “charring” can occur, where the energy absorbed in the substrate raises the local temperature of the material surrounding the absorption site high enough to cause thermal degradation of the polymer. The darkness or lightness of the mark is dependent on the energy absorbed, as well as the material’s unique thermal degradation pathway. By optimizing the laser setup, there is minimal surface carbonization residue.

A second surface reaction, “foaming,” is a chemical change effected through use of additives that release steam during degradation, resulting in foaming of the polymer. During the foaming process, the laser energy is absorbed by an additive that is in close proximity to the foaming agent. The heat from the absorber causes the foaming agent to degrade, releasing steam. Through tight control of the laser-operating parameters, high-quality and durable light-colored “white” marks can be generated on dark substrates.

A third reaction, laser energy (not shown), is used to heat/degrade one colorant in a colorant mixture, resulting in a color change. An example is a mixture of carbon black and a stable, inorganic colorant. When heated, the carbon black is removed, leaving behind the inorganic colorant. These mixed colorant systems are dependent on specific colorant stabilities, and not all color changes are possible. Carbon black formulations are integral in laser welding.

Laser additive chemistries for marking and welding
Near-infrared laser additives improve the degree of contrast, which can be further intensified by changing the laser setup parameters. Polymers possess inherent characteristics to yield “dark-colored” or “light-colored” marking contrast. Some colorant compounds containing low amounts of titanium dioxide (TiO₂) and carbon black also absorb laser light and can improve marking contrast. Each polymer grade, even within the same polymeric family, can produce different results. Additive formulations cannot be toxic or adversely affect the products’ appearance, physical or functional properties.
Compared to ink printing processes (pad/screen printing and inkjet), laser additives are cost-saving and can demonstrate 20 percent and faster marking speeds vs. non-optimized materials. Laser additives are supplied in pellet granulate and powder form. Granulate products can be blended directly with the polymer resin, while powder forms are converted to masterbatch. Most are easily dispersed in polymers. Based upon the additive and polymer, the loading concentration level by weight (in the final part) ranges between 0.01 and 4.0 percent.

Both granulate and powder form can be blended into precompounded color material or color concentrate. The selection of which additive to incorporate depends upon the polymer composition, substrate color, desired marking contrast color and end-use certification requirements. For extrusion, injection molding and thermoforming operations, precolor compounded materials vs. color concentrate yields better uniformity. Hand-mixing should be avoided. Mold flow and gate type/location are important factors. Homogeneous distribution/dispersion of laser additives throughout each part is critical to achieve optimal marking performance.

Some additives contain mixtures of antimony-doped tin oxide and antimony trioxide that can impart a “grayish” tint to the natural (uncolored) substrate opacity. Other additives can contain aluminum particles, mixed metal oxides and proprietary compounds. Color adjustments are made using pigments and dyes to achieve the final colormatch appearance. As commercially supplied, specific additives (also used for laser welding) have received FDA approval for food contact and food packaging use under conditions A-H of 21 CFR 178.3297 – Colorants for Polymers. For the European Union, there are similar compliance statements. Certification conditions are specific for polymer type, loading level threshold and direct or indirect contact. Further qualification of FDA-approved additives blended into a “final part” can achieve biocompatibility of medical devices.

During the laser additive loading/colormatch chemistry, it is not uncommon for a finished product to contain less laser additive than the calculated amount. This problem almost always relates to nonuniform distribution during extrusion or molding. Simple adjustments to the molding machine, such as increasing the back pressure and screw rotation speed, will resolve most issues. Homogeneous distribution/dispersion of laser additives throughout each part is critical to achieve optimal marking performance. For extrusion, injection molding and thermoforming operations, precolor compounded materials vs. color concentrate yields better uniformity. Hand-mixing should be avoided. Mold flow and gate type/location are important factors.

**Principles of through transmission laser welding**

The term “through transmission” derives from the fact that the laser passes through the laser-transparent upper part to the surface of the laser-absorbent lower part, as depicted in Figure 2. Three stages are involved in Through Transmission Laser Welding (TTLW) of plastics. In TTLW, the parts are pre-assembled and clamped together to provide intimate contact between their joining surfaces. In this article, high-power diode lasers (λ= 800-1,000 nm) and solid-state lasers (Ytterbium fiber and Nd:YAG laser, λ=1,060-1,080 nm) are utilized.

During the heating stage, the laser energy heats the laser-absorbent polymer at the interface, causing the part to expand, which increases the weld pressure. At the focus of the beam, the laser power is at its maximum and the part begins to melt at that point, creating a melt zone. This is the start of the second stage, the melding stage. Further expansion of the parts takes place, creating additional expansion with a corresponding increase in pressure. At this point, a small amount of welding has taken place.

The welding stage is the final stage. Sufficient molten material is generated to create a real weld. There is a collapse of the melted material, similar to that of hot plate or fusion welding. For most applications, this is on the order of 0.13 mm (0.005 in). Typical weld times are on the order of one to eight seconds for most applications, although larger parts can run longer. There are four principal TTLW laser welding processes: contour, mask, simultaneous and quasi-simultaneous welding.

The two parts to be welded must have different optical absorption properties at a given weld length. The top, laser-transparent part must transmit as much of the wavelength as possible while the bottom, laser absorbent part must absorb as much as possible in a thin layer. This results in the most energy-efficient combination because a high amount of energy is absorbed at the interface.
and it can degrade the top part before the bottom part is soft enough to weld. Excessive reflectivity also causes an increase in the amount of energy that is needed for welding.

Material suitability is more sensitive with laser welding than with any other joining process. Laser welding can theoretically weld all thermoplastics that are transparent to the laser beam. However, each polymer’s ability to transmit light from lasers of the three principle wavelengths used in laser welding is different. Furthermore, the response of a given polymer to laser beams will be altered by the presence of fillers, additives and pigments.

Materials with high absorption rates are ideal for the lower part in TTLW welding because they absorb most of the energy at the weld interface and create a thin, heated surface layer that is ideal for laser welding. Materials with absorption rates in the middle ranges can be a problem because they absorb the laser energy through the thickness of the material, and that results in heating of the whole material thickness. These materials allow very little energy through; therefore, they are poor candidates for the top material in TTLW laser welding. Furthermore, they do not absorb very much energy at their top edge and, consequently, make a poor selection for the lower material. Filled materials have been welded with up to 50 percent glass, but not for hermetic seals.

Principle advantages of TTLW include the following:

1. Noncontact welding. Laser welding uses a smooth, glass plate to hold the parts to be welded with a light clamping force of 100 lbs or less, and there is no contact with the welding instrument. Consequently, there is nothing to mar the surface of the welded parts, and there is no welding pressure required that could damage delicate parts.

2. Subsurface welding. The weld occurs at the interface between the two parts. The weld is nearly invisible with transparent parts and completely invisible with opaque parts. The weld can be just below the surface or deep in the parts.

3. Precise welding. The size and location of the laser weld can be very precise, and no vibration is transmitted to the part to be welded. For those versions of the process that require relative motion between the laser and weldments, it is the laser that moves. Consequently, laser welding is the most precise of the welding processes.

4. Minimal heat-affected area. The weld spot is very small and the heat-affected area is quite contained. As a consequence, it is possible to weld very close to other components without affecting them, permitting welding of subassemblies with sensitive and fragile parts previously emplaced. Furthermore, distortion and degradation due to heat are extremely limited, and residual stress is reduced.

5. Ability to weld dissimilar plastics. Dissimilar plastics that meet the necessary criteria can be welded to each other.

6. No flash. In laser welding, the weld is totally enclosed and no flash is created that must be trimmed off. There are no loose particulates.

7. Hermetic seals. Laser welding is capable of creating a hermetically sealed, gas-tight weld.

8. Energy efficiency. Relative to other welding processes, laser welding is highly energy efficient. This also means no excess heat is generated that must be removed from the workplace.

Conclusion
Dual-purpose laser additives incorporated into polymers yield superior marking contrast, line edge detail and speed. These additives optimize laser welding of similar and dissimilar thermoplastics. Advancements in affordable fiber laser technology have been instrumental. These benefits rapidly offset the incremental material additive cost. Optimized material-science chemistry for laser marking and welding requires expertise in polymers, colorants, pigments and dyes relative to solubility, particle sizes, threshold concentration limits, color match and regulatory certifications (GRAS, FDA Direct/Indirect Food Contact). Laser marking and TTLW of polymers meet the challenges of today’s applications.

References

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