COLORANTS AND SPECIAL ADDITIVES FOR LASER WELDING

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BIOGRAPHICAL NOTE

After studying chemistry at the Technical University Kaiserslautern (Germany), Sibylle Glaser finished her ph.D. at the BTU Cottbus (Germany). She worked as a post-doc in the group of Dennis Smith, jr. at Clemson University (SC, USA) in the area of chemical analysis of polymers. In May 2005 she joined Treffert GmbH & Co.KG where she specialises on colorants for laser welding and laser marking of polymers

ABSTRACT

In the last couple of years, laser welding of polymers has been a growing field of research and development, especially using laser wavelength in the near infrared as in diode lasers (e.g. 808 nm) or Nd:YAG-lasers at 1064 nm. The first additive for laser welding was carbon black resulting in a limitation in colour. Due to the development of special additives, the number of possibilities in colour design increased, first for opaque and now for transparent colours also.
In the laser welding process, two work pieces with different characteristics are essential: one should be IR-transparent and the other should absorb the energy of the laser beam. Colorants are an important aspect in case of these requirements. Common colorants especially pigments can absorb resp. reflect the laser light limiting their use in IR-transparent preparations. Treffert has developed a great number of colour recipes for these kind of applications resulting in a great expertise in laser welding.

PAPER

Introduction

Since the middle of the last century, plastics became more and more an alternative material to wood and metal. For example in the automotive industry where it is nearly impossible to build a car without using plastics. Over the years, a number of different types of synthetic plastics were developed with material characteristics for a wide variety of applications.
An additional aspect, next to quality and function of the products, is always the design. Beside the required functional properties, colour became the most important criterion in the quality control of plastic products.
In the German standard DIN 5033, colour is defined as a sense-impression mediated through the eye to differentiate two parts border to each other. So in industrial colouristic, colour is not an absolute value but a comparison between the coloured product and a defined reference or standard.

Colour

Now, what is colour? Colour is an individual perception which is stimulate by light received by our eyes. In physics, light is electromagnetic waves and a small spectrum of it, the range of 400 to 700 nm, can be seen by the human eye. The coloured objects are not self illuminating, therefore an extra light source is necessary. Its spectral power distribution across the wavelengths constitutes illumination. The object reflects a fraction of the wavelength of the light which is then detected by the eye of the observer and identified as colour. So, the colour stimulus produced by an object is a dual function of illumination and observation.
The illumination with different light sources has an influence on the observed colour, due to the spectral power of the individual light sources. Defined light sources are commercially available in so-called light boxes and used for colour matching. Examples for light sources are:

a. the norm light “D65” representing artificial sunlight
b. ”A” or “K2800” is tungsten light and
c. ”F11” or “TL 84” has the spectral power of fluorescent light.

Artificial light, such as Neon light, is not an ideal light source for colour matching.

For colour matching in the industrial colouristic of plastics, different light sources are used depending on the colour specification of the customer. This is necessary due to a known phenomenon called metamerism.
It describes that the colour of a metameric pair, like the standard and a sample, is the same in one light and different in another type of light. Metamerism occurs by using different kind of colorants. The most appropriate way to prevent this phenomenon is to match the colour in that type of light to which the object is exposed in use.

Colorants

The term colorant comprises all kind of coloured substances changing the appearance of a material. In the area of the colouring of plastics, there are two types of colorants: pigments and dyes.
Pigments can be of organic or inorganic structure and are insoluble in plastics, during processing as well as in the end product. Organic pigments normally possess a higher colour strength but less opacity than inorganic pigments. Additional factors for the colour strength of a pigment are the particle size and the dispersion in the matrix.
Dyes are organic molecules and dissolve in the medium of application. Therefore, no particles are visible and the transparency of the material remains unchanged.
Both pigments and dyes cover a wide range of properties as shown in Table 1.

Table 1 - Properties of inorganic pigments vs. organic pigments / dyes.

Properties	Inorganic Pigments	Organic Pigments /Dyes
Particle size	0.5 – 1.0 µm	0.01 – 0.1 µm / dissolve
Colour strength	low-moderate	high
Transparency	generally opaque	generally transparent
Heat resistance	high	low to high
Light fastness	moderate to excellent	low to excellent
Weather fastness	excellent	low to excellent
Migration	excellent	moderate to excellent / low to moderate
Plate-out	no	in function to the recipe
Dispersion	usually good	difficult / soluble

Laser welding of plastics

For laser welding of polymers an overlap geometry is normally used. That means that the laser beam penetrates an upper layer and the light is absorbed by a bottom layer. Laser joints can almost reach mechanical strength of the base material making them stronger than conventional joints. This motion- and contact free overlap welding process simplifies construction and produces welds without generating any micro particles on the component's surface. Four optical parameters (absorption, reflection, transmission and scattering) have to be considered in the physics of laser welding. The addition of colorants and/or certain additives can have an effect on these optical factors. The laser welding process can be influenced or controlled by choosing suitable colour formulations.
Requirements for the overlap welding process are that the first part has a sufficient transparency for the laser beam and the second part is enabled to absorb the beam and transform the light into heat energy forming a welding seam.
Most polymers show absorption in the UV and IR range. In the near infrared (NIR), a wavelength area in which most laser welding systems are operating, and in the visible the polymers are transparent or show a milky white translucent behaviour (see Figure 1). Due to optical scattering, semi-crystalline polymers, like PBT, present a noticeably lower transparency in comparison with amorphous polymers.

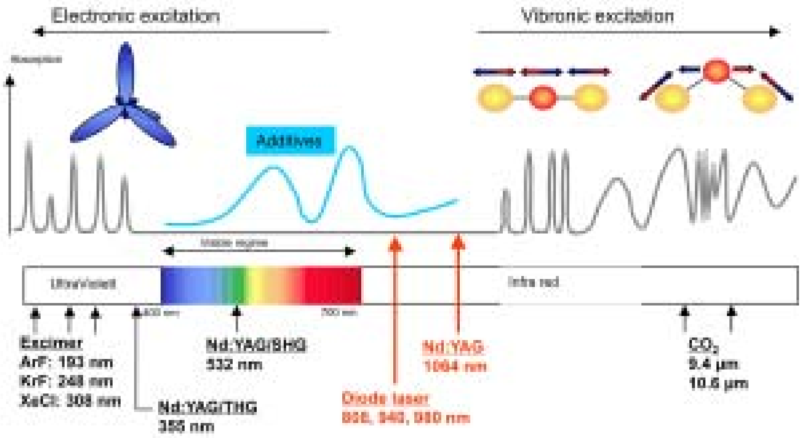

Figure 1 - Interaction between polymer and light.
The grey curve shows the typical absorption of a polymer. Introducing additives leads to an interaction in the visible and near IR range.

In conclusion, for NIR-transparent parts colorants and additives should not affect the transparency or the material by absorbing, reflecting or scattering the laser beam and for NIR-absorbing parts special additives are needed to absorb enough energy to achieve a welding seam.

Colorants for NIR-transparent parts

The requirements for colorants in laser transparent parts are high transmission and low reflection and absorption values. Dyes meet all these requirements as can be seen in Figure 2. They are soluble in the matrix which means there is no light scattering and the transmission in the near IR is similar to the transmission of the base material, i.e. dyes don't have any influence on the transmission. They show good dispersion properties and colour strength but unfortunately, the number of dyes, in particular for the use in high temperature materials, is restricted.

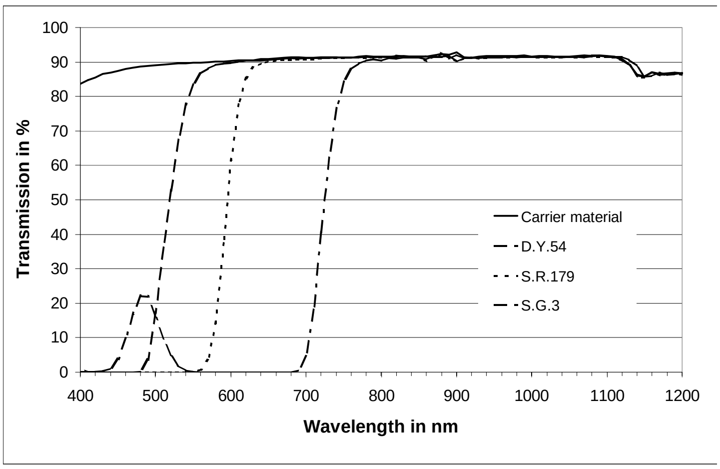

Figure 2 - Transmission of selected dyes.

Due to having nearly no reflection, absorption or scattering, it is not possible to achieve opacity. Therefore, organic and inorganic pigments are necessary in the formulation of opaque colours. Organic and inorganic pigments show different behaviour in the near IR. Inorganic pigments are less transmissive and the light scattering is often a problem. In Figure 3 four types of Pigment Red 101, an inorganic ferric oxide, are shown. The four types differ in particle size and treatment at production resulting in big differences in transmission.

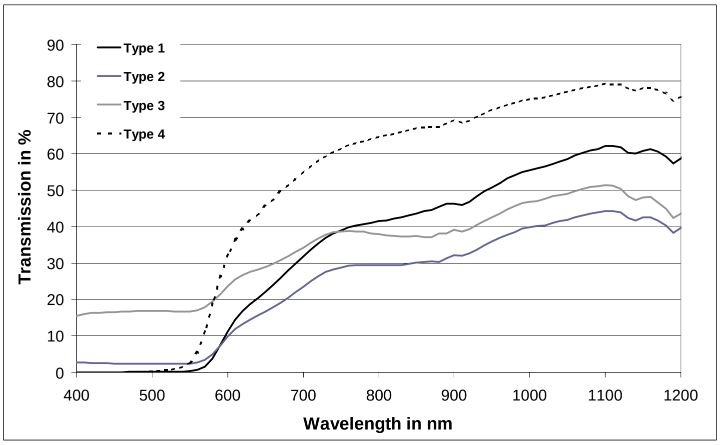

Figure 3 - Transmission of different types of P.R.101. *The same concentration and material thickness were used for the measurements.*

The more transparent organic pigments are stronger in colour but often can't be used in high temperature thermoplastics. So, knowledge about the behaviour of the colorants in the NIR beside their characteristics in the visible range is important in the creation of NIR transparent colours.

Colorants for NIR-absorbing parts

As mentioned above polymers are not able to absorb light in the near IR without adding special additives. This kind of additives usually have an intrinsic colour of their own in the visible range. The ideal laser additive should exhibit high absorptivity at common laser wavelength in the near IR without having any absorption in the visible range (i.e. no residual colour) and without optical scattering.
Carbon black (CB) was the first pigment used as absorber and it can be used with all types of laser (808, 940, 980, 1064 nm,…). The concentration of CB depends on the melt temperature of the polymer to weld: the higher the melt temperature the higher the CB concentration needed. The disadvantage of CB is its colour so that in result it can't be used in applications of bright or transparent colours.
Therefore, special dyes were developed, e.g. Lumogen® IR (BASF).

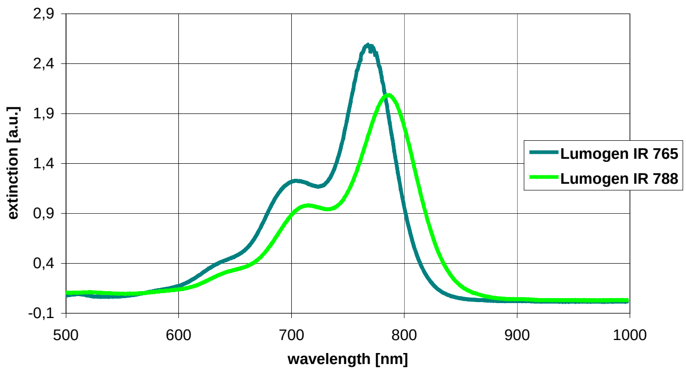

Figure 4 - VIS/NIR-absorption spectra of 3 mm poly-carbonate sheets, with 100 ppm of Lumogen® IR 765 and Lumogen® IR 788 added.

The choice of the laser wavelength for an optimal absorption, i.e. optimal laser welding, depends on where the maximal extinction coefficients of the absorber additive is located in the wavelength range. In Figure 4 the absorption spectra of both types of Lumogen® IR are shown with a maximum of extinction around 800 nm, so a diode laser at 808 nm should be used. The absorbers were tested for a wide range of polymers, from standard polymers (polyolefines) to engineering plastics (polyamides, ABS,..) up to high-quality polymers (PSU, PEI, PEEK). The low residual colour and the high transparency of the dyes allows the formulation of nearly all transparent shades and the reproduction of non-transparent or opaque colours.
Some inorganic laser absorber additives are also known, but the dispersibility of those products in thermoplastics is not without problems.

Masterbatches – from additive to laser optimised polymer

Considering the importance of good dispersion for achieving high quality colour, it is clear that the "delivery" system or form in which the colour is supplied to the processor is of vital importance. The production of laser-suitable polymers with optimised colouring usually requires a masterbatch producer. In masterbatches pigments and dyes and/or special additives are optimally dispersed at high concentration in a single carrier resin, a polymer similar in nature and type to the material to be coloured. Custom colours with required laser welding properties as NIR-transparency or absorption can be specifically formulated.

Nearly no limit for colours

Until a few years ago, while using common absorbers, dyes and pigments, only a few configurations could be achieved, especially dark colours. Using absorbers, such as Lumogen® IR, the number of possible colours increased to nearly all colours. In Figure 5 the increasing degree of complexity in overlap laser welding is shown.

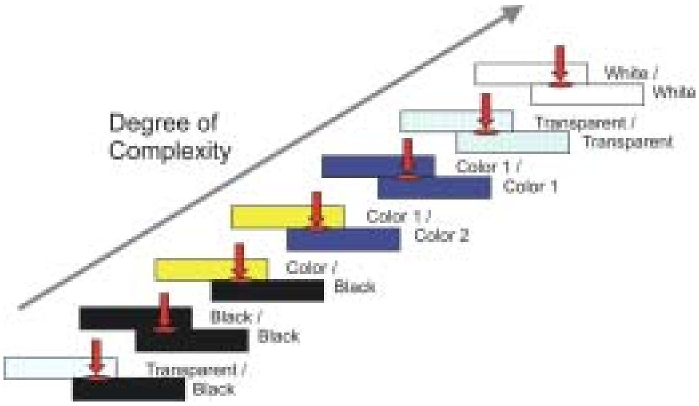

Figure 5 - Degree of complexity.

The first and most simple version is the welding of the uncoloured base material on a part filled with carbon black. Welding black on black was an important problem in the beginning of laser welding. Carbon black couldn't be used due to its excellent absorption properties. The formulation of a NIR-transparent black is at the moment done by colour matching different colorants achieving a black colour in the visible and transparency in the NIR. New black NIR-transparent colorants are still under development.
In the welding of parts having the same colour, metamerism was always a problem. Different colorants have to be used in laser transparent and laser absorbing parts. By using a nearly transparent absorber, it is possible to avoid metamerism. By adding the absorber into one part, the same colour recipes can be applied in both parts without changing colour.
Brilliant white absorbing parts are still a challenge due to the optical properties of the colour itself. White is the reflection of all light. Titanium dioxide is the only colorant to achieve a bright white colour. But it has also strong reflecting and light scattering properties. By conditioning of the material using an absorber, a relatively bright white (RAL 9003) can be obtained. Opaque white transmissive polymer is still hard to achieve due to the light scattering This is yet the only situation that can not be imagined, regarding colour configurations.

Conclusions

Laser welding of polymers is still a growing field of joining thermoplastic materials. Colorants and absorbers are an important factor in this process. Knowledge about the behaviour of pigments and dyes in the near IR is important for the development of laser transparent and laser absorbing formulations.
Due to transparent absorbers additives, a broad range of colours, from transparent to opaque and from bright to dark, can be offered.
Treffert has developed a great number of colour recipes for all kind of applications resulting in a great expertise in laser welding.