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Technical Information for Experts 02/00e

Transmission laser-welding of thermoplastics

■ Laser welding of thermoplastics is a new jointing technique with a host of advantages. It is not only another extremely useful welding method but also a cost-effective alternative to traditional techniques involving screws or adhesives. ■ Because only the region of the joint is heated and there is no mechanical stress, the process is suitable even for particularly sensitive components – in electronics or medical technology, for example. ■ This technical information describes the principle of laser welding and some variants of the process, and also the requirements placed upon materials. Tables show which grades within the various families of polymers are suitable for the process. ■

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Transmission laser-welding of thermoplastics

As a tool for jointing plastics the laser is still new, but this industrial application is likely to become as well established as laser marking and laser cutting. Materials welded to date using lasers have mainly been plastic films, and the process has only recently been extended to the jointing of three-dimensional components for the mass-production of parts.

The process technology for laser welding of thermoplastics has many advantages when compared with traditional welding methods, such as heated tool welding, vibration welding or ultrasonic welding:

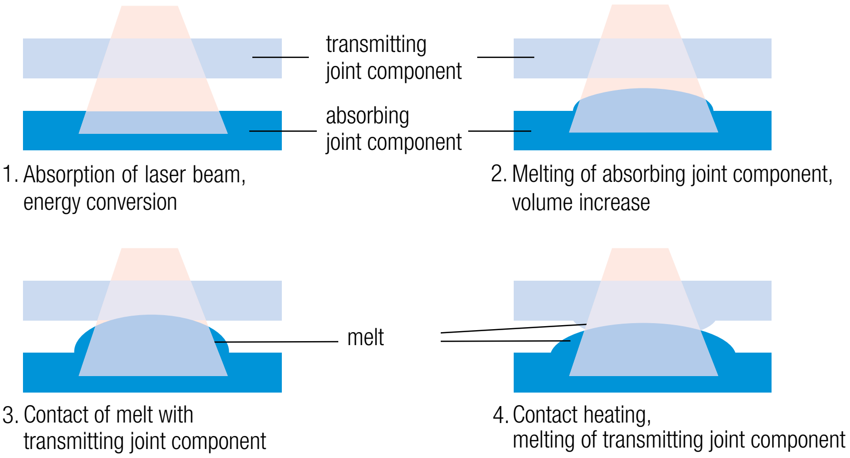
- no mechanical stress on the joint components
- small amounts of heat applied to a limited area
- parts with different stiffness are weldable
- contactless (no melt tack, no markings on components)
- virtually no erosion process
- repair welds possible
- materials of different viscosities can be welded

These advantages have to be weighed against the fact that welding by traditional methods is less sensitive to polymer material, processing history, pigmentation and additives.

Easily the mostly used variant of the process to date is transmission or overlap welding.

Principle of transmission welding

The jointing process in laser welding is based on converting radiant energy into heat via its absorption within the material, giving local melting in the jointing region **(Fig. 1)**. The basic requirement for the transmission process is therefore a suitable combination of materials.



1. Absorption of laser beam, energy conversion
2. Melting of absorbing joint component, volume increase
3. Contact of melt with transmitting joint component
4. Contact heating, melting of transmitting joint component

Fig. 1: *Schematic description of procedures during transmission welding*

The short-wavelength IR radiation is intended to pass virtually unhindered through the upper transmitting joint component and become completely absorbed at a depth of from 0.1 to 0.5 mm within the lower joint component, becoming converted into heat (1).

This joint component is heated and melted in the absorption region by the energy supplied, (2). Melting increases the volume and bridges the joint gap. Contact enables heat transfer between the two joint components (3). The laser-permeable joint component also becomes melted by conducted heat (4).

Optical properties of polymer materials

Intensity of absorption is determined by the material and also by its additives, as well as by the wavelength emitted by the laser source. The radiation optics of the materials can be controlled as required within certain limits by modifying the materials appropriately. Absorption spectra give information on the conversion of incident energy as a function of wavelength.

Reflectance and transmittance are given as a function of wavelength in reflection and transmission spectra **(Fig. 2)**.

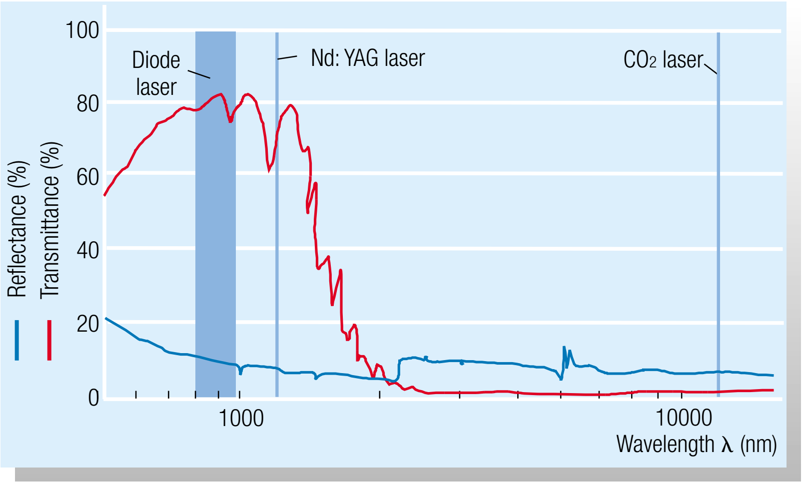


Fig. 2: *Reflection and transmission spectra for an Ultramid®A sheet of 2 mm thickness*

Radiation sources (lasers)

The degree of transmission required means that the main radiation sources for transmission welding of plastics are those emitting in the short-wavelength infrared **(Fig. 2)**:

- solid-state lasers (Nd:YAG-Laser; λ = 1064 nm) and
- high-power diode lasers (λ = 800 –1000 nm).

Medium- and long-wavelength IR radiation is completely absorbed close to the surface of all polymers, whatever their content of fillers or additives. This means that CO_2 lasers (λ = 10600 nm) are restricted to film welding.

The latest generation of high-power diode lasers features compactness, cost-effectiveness and high efficiency, but these lasers have limited focusing capability and are therefore not suitable for every variant of the process.

Variables and significant process parameters

Low-absorption thermoplastics have good suitability for laser welding if they are combined with an absorbing and chemically compatible material. The laser power and laser-permeable material for transmission welding therefore need to be selected to make the transmitted energy density of the laser beam sufficient to melt the absorbing material.

The depth to which the laser beam penetrates the plastic depends on a wide variety of variables **(Fig. 3)** such as

- wavelength of the laser beam
- chemical composition
- morphology, and
- the nature and amount of additives (fibers, colorants, plasticizers and fillers).

a) Morphology

Amorphous thermoplastics absorb only a small proportion of the incident laser beam, and theoretical penetration depths of 100 mm and more can therefore be achieved. The optical properties of semi-crystalline thermoplastics are quite different: the secondary crystalline structures present (e.g. spherolites) scatter the laser beam.

b) Fillers and reinforcing materials

Engineering plastics generally have fillers and reinforcing materials which can scatter or even absorb incident IR radiation. Although glass fibers themselves are permeable to IR radiation, scattering of radiation at the many interfaces between the fibers and the matrix increases the optical path and thus reduces transmission. **Fig. 4** shows the effect of glass fiber content on the transmission, reflection and absorption behavior of Ultramid® A (polyamid-6,6).

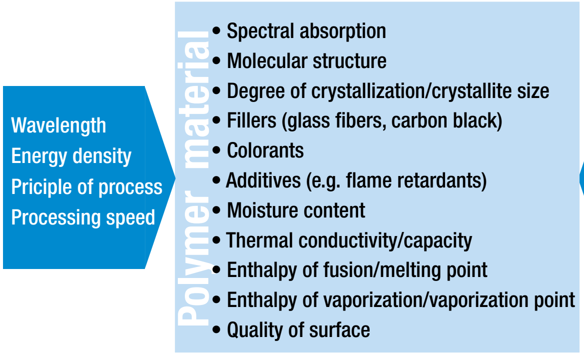


Fig. 3: *Factors affecting depth of penetration of laser beam and the joint quality*

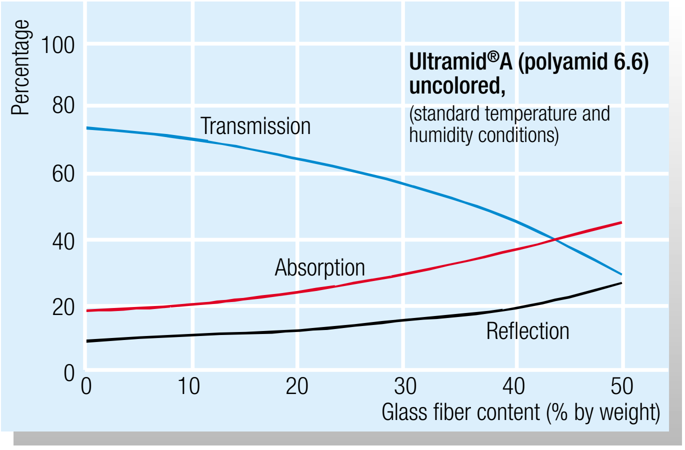


Fig. 4: *Effect of glass fiber content on transmission, reflection and absorption in polyamid-6,6*

In coloured plastics the content of pigment or dye plays an important part **(Fig. 5)**. The lower the penetration depth, the greater the risk of damage to the material. At lower pigment contents, relatively deep melting of the absorbing joint part is likely to be possible without thermal damage to a material. The resultant increase in volume expansion lengthens the period of melt contact and thus increases weld strength. Absorption and transmission behavior can therefore be adapted by incorporating fillers and/or pigments - even to the extreme of surface absorption within a layer just a few micrometers thick.

Controlled incorporation of specific additives can produce coloured plastics which to the eye appear identical but actually have the different absorption behaviour needed for transmission welding.

c) Process parameters

Taking feed rate and laser power a natural limit can be expected to apply - above which a good-quality weld can no longer be obtained. Since the diffusion process required for welding needs a certain period for the high temperatures to act, problems will result if the feed rate is too high or the laser power too low. On the other hand, damage of the material can result if the feed rate is too low or the laser power too high.

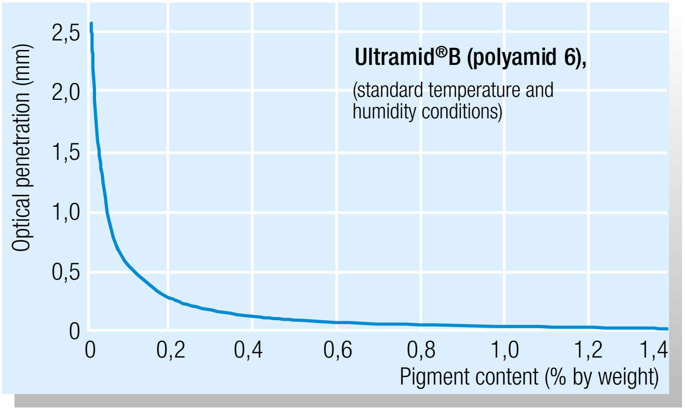


Fig. 5: *Effect of pigment content on optical penetration depth in polyamid-6*

Suitable materials

There is a wide variety of amorphous thermoplastics with ideal transmission properties **(Tab. 1)** in the wavelength region usually used:

- PS
- ABS
- SAN
- PMMA
- PSU/PES

In contrast, semi-crystalline thermoplastics such as

- PA
- PBT
- POM

can absorb resp. reflect a considerable proportion of the laser energy, even without additives.

Although the position initially appears unfavourable for the PA and PBT polymer families particularly important in industrial applications, there are suitable Ultramid® and Ultradur® grades for laser welding, which can be used without restriction up to customary wall thickness of 2 mm **(Fig. 6)**.

Table 1: Suitability of various thermoplastics for laser welding

	Optical properties	**Welding performance**
Polystyrene (PS)	++	++
Polyamide (PA)	+	++
Polybutylene terephthalate (PBT)	0	+
Styrene-acrylonitrile (SAN)	++	++
Polyethersulfone (PES)	++	++
Acrylonitrile-butadiene-styrene (ABS)	+	++
Combination PC and ABS	++	++
Combination PMMA and ABS	++	++

++ = very good, + = good, 0 = satisfactory

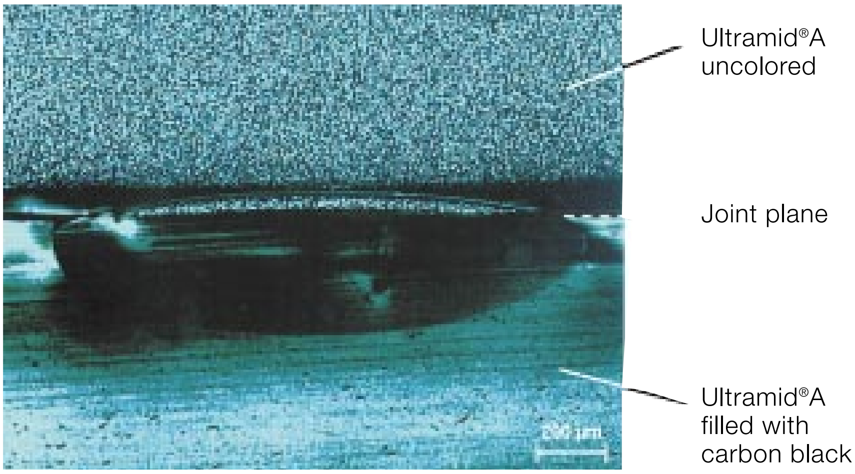


Fig. 6: *Micrograph of a weld produced by laser welding*

As well as welding of thermoplastics of the same type it is also possible to join different types, such as polyamid-6 and polyamid-6,6. Combinations with commercially available thermoplastic elastomers are also possible.

Variants of the process

Nowadays several process variants are available, all based on the transmission principle, and the requirements of each case determine which variant is most useful **(Tab. 2)**. The processes are described below together with their typical features.

a) Contour welding

Contour welding is a sequential welding process in which either the laser beam is guided along a freely programmable weld profile or the component is moved relative to a fixed laser **(Fig. 7)**.

For this process variant there are fiber-coupled laser systems with a rounded beam cross section. Depending on the type of laser and the optics, the width of the weld can be varied between tenths of one millimeter and several millimeters.

The process can weld components with complex, three-dimensional joint contours. It also allows rapid changeover between components of different shapes.

Since the melting of the weld takes place sequentially no melt flow-out is possible, and therefore only a small joint gap is permissible. As the weld length increases the resultant process times are several seconds.

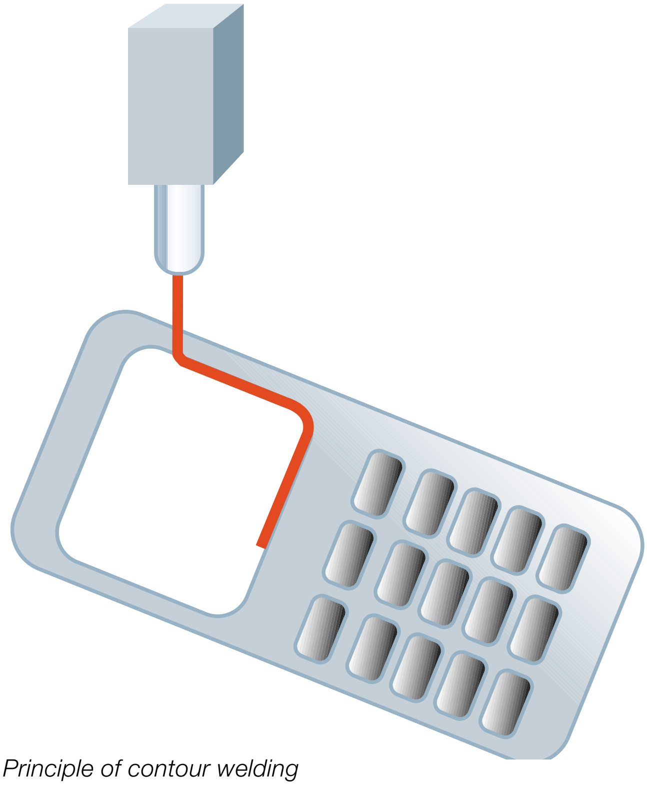


Fig. 7: *Principle of contour welding*

b) Simultaneous welding
In simultaneous welding, radiation from individual high-power diodes is emitted in the shape of a line arranged along the contours of the seam to be welded **(Fig. 8)**. The entire profile is therefore melted and welded simultaneously. The number of diodes required depends on the dimensions of the component and on the welding power needed.

The process requires no relative movement between component and laser beam, and there is no need for any system for guiding the beam. On the other hand, a new arrangement of laser diodes or a new welding tool is needed for each change of weld profile or design, and the shape of the weld is currently still restricted to profiles composed of straight lines.

Melt flow-out can be produced by applying pressure to the weld profile during the welding process. This can compensate for warpage, component tolerances or sink marks in the region of the weld.

Simultaneous welding features very short process times of less than 2 seconds, and is therefore particularly suitable for mass production.

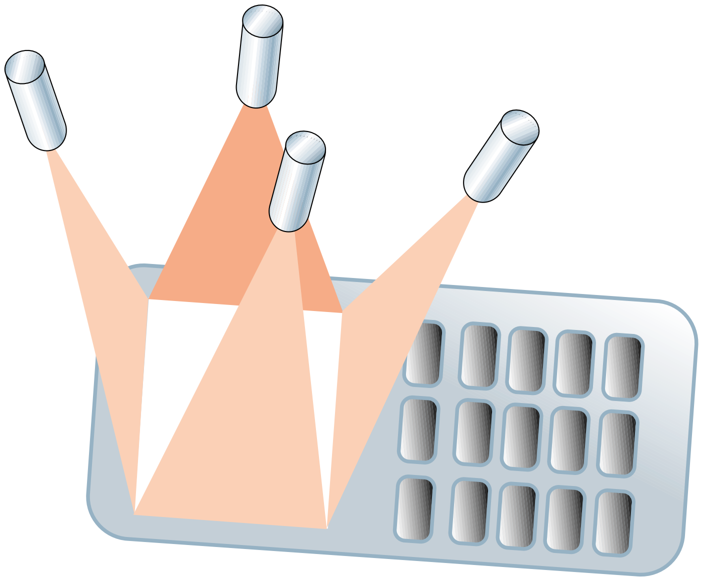


Fig. 8: *Principle of simultaneous welding*

c) Quasi-simultaneous welding or scan welding
Quasi-simultaneous welding is a combination of contour welding and simultaneous welding. Galvanometric mirrors (scanners) are used to guide the laser beam along the weld profile at a very high speed of 10 m/s or more **(Fig. 9)**. The high speed of transit gives progressive heating and melting of the region to be welded. Unlike with simultaneous welding, there is high flexibility for changes in weld profile.

Application is currently restricted to components with dimensions of not more than 200 mm x 200 mm and virtually planar weld profiles. As in simultaneous welding, pressure can be applied during the welding process to make the melt compensate for moulding tolerances. Process times are longer than with simultaneous welding, but shorter than for contour welding.

The use of long deflection paths and scanner mirrors demands a laser source with high quality of beam. Nd:YAG-lasers are therefore used.

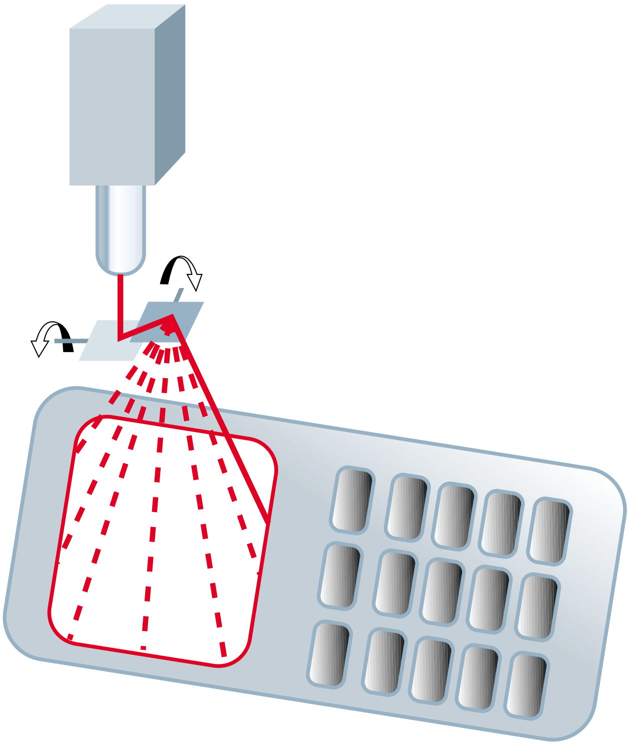


Fig. 9: *Principle of quasi-simultaneous welding*

d) Mask welding

Mask welding is the newest process. A linear laser beam is made to traverse the parts to be joined and a mask is used to screen specific areas from the beam, so that it impacts the jointing surface only at the areas to be welded **(Fig. 10)**. The process can produce very precisely positioned welds.

Very fine structuring of the mask can be used to achieve extremely high resolution, and welds just 10 µm in width can be produced. Straight and curved lines of various widths can be produced in a single operation, and sheets can also be welded. This variant of the process is therefore used mainly for sensors, chips, electronic components or micro-system technology. However, changes in the shape of the weld require production of a new mask.

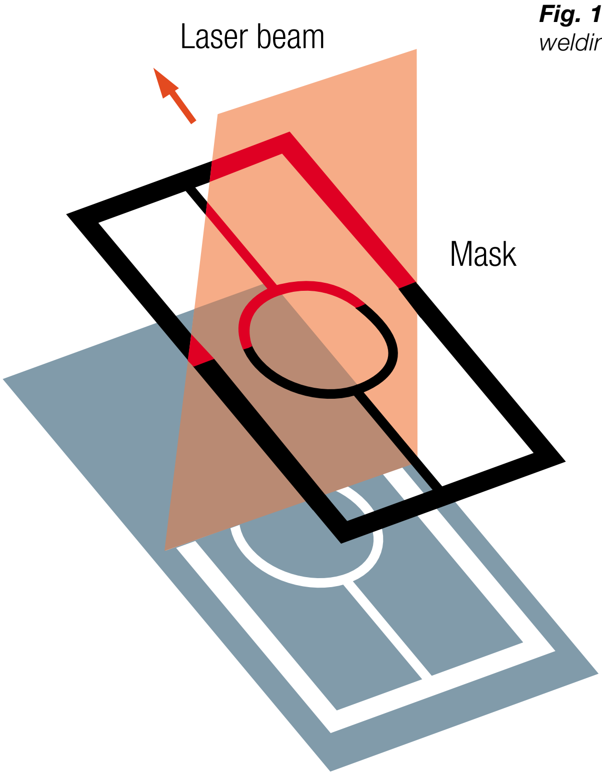


Fig. 10: *Principle of mask welding*

Table 2: Comparison of process variants

	Contour welding	Simultaneous welding	Quasi-simultaneous welding	Mask welding
Flexibility	very high	low	high	low
Welding time	long	short	moderate	moderate – long
Complexity of weld profile	very high	moderate	high	moderate
Tolerance compensation	none	possible	possible	none
Plant cost	moderate	very high	high	moderate – high
Laser type usable	Nd:YAG; diode	diode	Nd:YAG	diode

BASF Product line

The product combinations in **Table 3** give quality level comparable with those from traditional processes.

For the transparent Terlux® and Ultrason® materials the method is technically elegant and gives a perfect welded seal, e.g. for displays. Welding uncoloured and black components gives a colour combination which is highly suitable for many applications.

Specific IR-transmitting black Ultramid® and Ultradur® grades have been developed for components whose appearance is important **(Tab. 4)**. This means that even laser-welded components in uniform black are possible.

Although fundamentally PBT is not ideal for laser welding, and coloration always leads to some degree of absorption, black Ultradur® grades can give satisfactory welding at customary wall thickness of 2 mm, even with 30% glass fiber content. The strengths achieved here are just as high as with ultrasonic welding, for example.

Table 3: Product combinations suitable for laser welding

Transmitting Component Uncolored	Absorbing Component Black
Ultramid®	
A3K	A3K sw 464
A3W	A3W sw 464
A3WG6	A3WG6 sw LS 23189
B3WG6	B3WG6 sw 564
B3WG6	B3EG6 sw LS 23189
T KR4350	T KR4355G5 sw 564
T KR4355G5	T KR4355G5 sw 564
Ultradur®	
B4300G2	B4520 sw 00110
B4300G4	B4520 sw 00110
B4300G6	B4520 sw 00110
B4300G6	B4300G6 sw 15073 Q16
B4300G10	B4520 sw 00110
B4520	B4520 sw 00110
S4090G6	S4090G6 sw 15077
Ultraform®	
N2320 003	W2320 003 sw11020 oder sw 120
S2320 003	W2320 003 sw11020 oder sw 120
W2320 003	W2320 003 sw11020 oder sw 120
Ultrason®	
E2010	E2010 sw 10018
Terlux®	
2802 TR	2802 TR
Luran® S	
KR2864C	KR2864C
776 S	776 S oder 2866 C
777 K	777 K oder 757 G
757 G	777 K oder 757 G
2861/1C	757 G oder 2866 C
2864 C	777 K oder 757 G
2863 C	2866 C
797 S	777 K oder 2866 C

Table 4: Combinations of black plastics suitable for laser welding

Transmitting Component Black	Absorbing Component Black
Ultramid®	
A3WG6 LT sw*	A3WG6 sw LS 23189
B3WG6 LT sw *	B3EG6 sw LS 23189
Ultradur®	
B4300G6 LT sw *	B4300G6 sw 15073 Q16

* LT: specific coloration with laser transparency

Safety and the environment

When correct procedures are used to weld polymeric materials the amounts of gaseous emissions produced are generally very small. Nevertheless, installation of adequately sized extraction and filtration systems is recommended, since alongside the main constituents of the exhaust gases - the nonhazardous CO_2 and H_2O - small concentrations of toxic constituents can be present.

The handling of lasers must always comply with appropriate regulations - such as those relating to employee safety requirements - since even scattered radiation from a laser can damage eyes and skin.

Note
The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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WIS 0003 e 01.2001