Laser Plastic Welding

Design Guidelines Manual

Rev. 3.1

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Introduction

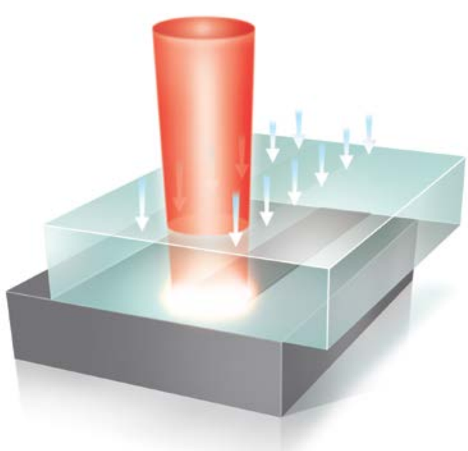
The purpose of this document is to outline the necessary guidelines of laser plastic welding in order to equip designers and engineers with the knowledge they require during the concept and design phase of new products.

Please understand these are only guidelines and each specific application will have its own set of nuances and variations from these guidelines. We recommend you consult an LPKF specialist during your design process.

Laser Welding Process

Laser plastic welding is a method of bonding two or more thermoplastic components together. Although there are many methods for joining thermoplastics, laser plastic welding has a few clear advantages: higher joining quality, minimal resulting flash or particulates, higher quality controls, less stress to the component and can weld complex and intricate shapes.

The process relies on passing laser energy through an upper transmissive layer down to the surface of the lower layer where the energy is absorbed. The resulting heat melts the plastics and creates a weld seam.



There are four important requirements for the laser welding process to occur. These four points will be addressed in detail in the following section.

The Big Four

1. Laser Transparent Top Layer
Most thermoplastic resins are laser transparent in their natural state (no additives). Note that “laser transparent” should not be mistaken for “optically transparent” since laser welding radiation sources are outside of the visible light spectrum for the human eye. In fact, most laser welding applications today utilize a laser transparent top layer which is opaque to the human eye.

The upper joining partner must be designed transparent for wave lengths in the range of 808nm – 980nm, the lower joining partner absorbent for this wavelength.

There are several influences on the laser transmission including but not limited to: additives (UV stabilizers, colorants, heat stabilizers), fillers (glass fiber, carbon fiber, blowing agents) and thickness.

Only a percentage of the laser energy needs to transmit through the top layer for the welding process to occur, the rest of the energy will be absorbed, reflected, and scattered before it reaches the weld joint.

A minimum transmission rate of 5% is required. This rate assumes your material measurement will be taken using an LPKF TMG device, as other companies use different measuring methods and will therefore require different transmission rate guidelines.

2. Laser Absorbing Bottom Layer
The laser absorbent layer is responsible for turning the remaining laser energy, once it has passed through the transparent top layer, into heat at the surface of the absorbing layer.

To make a plastic absorbent, the typical additive used is carbon black at an amount usually between 0.2 and 0.4% by volume. Most major resin manufactures use carbon black to make black resins economically.

Ideally, the transmission rate of the absorbing partner should read absolute zero. In this way all of the energy would stay at the surface of the absorptive layer where it is required to create a weld. Darker colors will absorb more effectively than lighter colors.

It is possible to weld two pieces of clear plastic to one another. There are two such methods for this. A specialized additive, called Clearweld™, by the Gentex® company offers an optically clear additive that is also laser absorbent.

The second method does not require any coatings or additives, instead special laser wavelengths are used to achieve absorption. This process may not work with every application, but it does add flexibility for applications looking to minimize additives.

In regards to plastic coloring, the company BASF® has an additive called Lumogen™ which is used to make laser absorbent resin in a variety of colors. Colored laser transparent top layers are also possible.

A note about white plastics: most often white color is created using titanium oxide (TO2) additives. Infrared laser light is highly reflective to TO2 and plastics colored with TO2 may not be able to absorb adequately.

However, the plastics company Orient® has created a special additive that allows white coloring without the use of titanium oxide, see Table B.2 on page 14 for details.

3. Material compatibility

The two polymers, which are to be joined, must be of the same plastic family with similar resin properties and melting temperatures to be joined successfully; otherwise one part may melt or burn and the other will be unaffected.

It is safe to note that it is possible to weld the most common thermoplastics, such as: PA 6, PA 66, POM, PBT, PC, ABS, PP and PE in their pure form.

Table 1 below, outlines the miscibility of various plastics. A larger, more detailed list of compatible plastics, with bond qualities, can be found in the appendix in Table B.1 on page 13.

	PS	PS imp. res.	SAN	ABS	PA	PC	PMMA	POM	PVC	PP	PE-LD	PE-HD	PBT	PET
PS	+	+												
PS impact resistant		+												
SAN			+	+		+	+		+					
ABS			+	+		+	+							
PA					+									
PC			+	+		+	+						+	+
PMMA			+	+		+	+		+					
POM								+						
PVC			+				+		+					
PP										+				
PE-LD											+	+		
PE-HD											+	+		
PBT						+							+	
PET						+								+

Table 1 – Compatibility of plastics

4. Contact

It is paramount that heat energy, generated on the surface of the lower layer, be transferred to the upper layer so that it may become molten as well. In order for conduction to occur the two layers need to be in contact during the welding process to ensure proper heat conduction.

Contact is accomplished with various methods of clamping devices or special component designs (radial welds specifically); the Clamping Overview section will cover this in detail.

Clamping will help minimize any gaps caused by improper part design or tolerances, but every effort should be made to have accurate parts prior to welding.

Process Methods

LPKF systems utilize four main process types of laser plastic welding: contour, simultaneous, quasi-simultaneous and hybrid. The laser staking method described below is actually a form of simultaneous welding, but warrants separate mention.

Contour Welding
In this process the laser beam, focused into a point, moves relative to the component making a single pass over the joint. The width of the joint line can vary from a few tenths of a millimeter to several millimeters. Contour welding is especially suited for large parts or three dimensional parts and radial welding.

- Pros: very flexible, excellent process quality monitoring
- Cons: slower cycle times compared to other laser process methods
- Systems: Integration, Power, Vario or TwinWeld 3D

Simultaneous Welding
Simultaneous welding is where the entire weld seam is heated at the same time. Using specially designed fiber-optics, the laser energy is formed into the pattern of the weld seam and projected onto the entire seam simultaneously. There is no relative movement of the laser or the device. This method is ideal for high volume runs that require ultra-low cycle times.

- Pros: fast cycle times
- Cons: expensive as multiple laser sources are typically required, small working area (50mm x 50mm), less precise process monitoring
- Systems: Integration, Power, Vario or Spot

Quasi-Simultaneous Welding
Quasi-simultaneous welding is a combination of contour and simultaneous welding. A single, focused laser beam is guided by a mirror, tracing the weld path multiple times at very high speeds. In this way the entire joint line is effectively heated simultaneously.

- Pros: fast cycle times, excellent process monitoring, flexible
- Cons: For mainly two dimensional parts
- Systems: Integration, Power, Vario

Hybrid Welding
Hybrid welding uses high-powered halogen lamp energy to assist the laser in the welding process. The halogen lamps pre-heat the plastic around the joint line, in effect requiring less laser energy to melt the plastic. The benefits of pre-heating are faster cycle times as well as reduced part stress from temperature shock. The halogen light is polychromatic so it will be absorbed by, and heat, both the upper and lower layers.

- Excellent process monitoring, increased cycle times, uses less laser energy, improved gap bridging, increased seam strength
- Specs: halogen lamp projects an 8mm zone around joint seam
- System: TwinWeld 3D

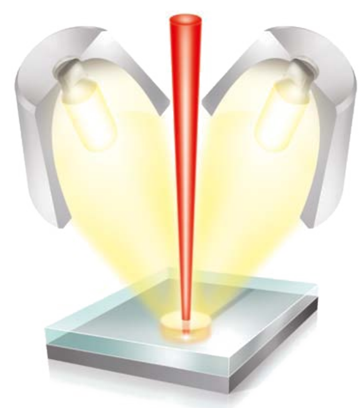


Image 1 – Hybrid welding process

Laser Staking
Laser staking is an LPKF patented method and is actually a form of simultaneous welding. Laser staking is essentially riveting using laser plastic welding technology.

Commonly used for fastening circuit boards to plastic housings, small plastic discs are positioned over a prong which projects through a mounting hole in the printed circuit board. Laser energy is applied to the interface between the disc and the injection molded prong. As pressure is applied the prong and disc fuse together to hold the circuit board in place.

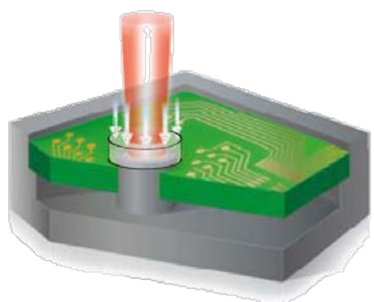


Image 2 – Laser staking diagram

- Highlights: requires no contact with the delicate electronics, clean, equipment is small and easily integrated into an existing production line
- Systems: LQ-Spot

Part Design and Joint Configuration

Please take the following factors into consideration when designing your component for laser plastic welding.

Overall Component Size
LPKF laser plastic welding systems can handle components a few centimeters in size up to a total workspace requirement of 1,200mm^2 (47in^2). See Table B.3 on page 14 of this document detailed workspace specifications of each LPKF system.

Weld Size and Spacing Capabilities
Laser beam focal points sizes can range from 0.6mm – 3mm resulting in a weld seam width of corresponding size.

Beam Accessibility
The component and clamp tooling should be designed to allow adequate access of the laser beam to the weld seam.

Obstructions, such as side walls or clamp tooling or will block the laser entirely; while even channels, voids or molding gates within the plastic may result in shadowing effects.

Beam accessibility dimensions can be calculated as follows: weld seam width (rib width) + positional tolerances + dimensional tolerances.

Where positional tolerance is the allotted movement of the component during clamping and dimensional tolerance is the allotted size difference for variations in sizes from component to component.

Beam accessibility should also consider the cone-shape of the laser beam and the beam angle. Because the beam is projected off of a set of mirrors it can enter the plastic at an angle of 90° +/- 15°.

In the image below you can see a tapered side-wall, which had to be adjusted to account for beam shape and angle.

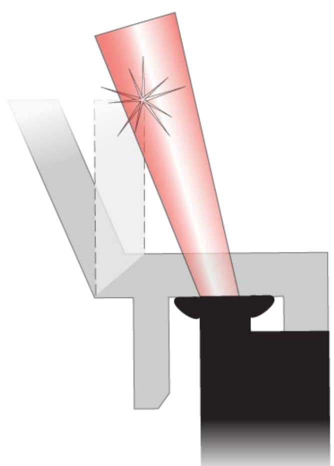


Image 3 – tapered side-wall for beam accessibility

Molding gates should be designed outside of the joint path, as variations in material density, at and near these points, will cause fluctuations in the amount of laser energy reaching the interface, in turn resulting in burns or underdeveloped areas in the weld.

Transparent Upper Layer Thickness
Material designed too thick may result in a lack of energy reaching the interface while material that is too thin may not be strong enough or have enough volume to successfully absorb adequate heat for welding.

We recommend a thickness of 0.8 to 1.8mm. However, successful welds have been created through higher and lower values dependent on material combinations.

A good rule to follow is to match the depth of the top layer with the width of the raised rib (described later).

It is recommended that the transmissive layer have a consistent thickness. Fluctuations in thickness will affect the amount of laser energy transmitted along the interface resulting in burning or underdeveloped seam spots.

Melt-Collapse
Melt-collapse, also called *melt-travel* or *joint path*, is the distance the joining partners travel as they move together under clamping pressure. An ideal collapse will fall in the range of 0.1mm to 0.5mm. Image 7 on page 8 shows a common lap joint prior to melt-collapse. The following image, Image 8, is the same joint after melt-collapse has occurred.

Avoid trying to bond two flat plates together due to the extreme amount of pressure required to have the plates mate properly.

If two flat pieces are to be joined, it is recommended that a raised rib be designed into the bottom piece. This rib will allow for melt collapse to take place without the need for extreme clamping pressure. See letter "*F*" of Image 7 on page 8.

Mechanical limiting stops are molded into one or both of the joining parts. These will ensure a consistent melt-collapse as well. These are not commonly recommended as they may lead to internal stress after the parts cool, see letter "*G*" of Image 7 on page 8.

Melt-collapse is a function of the amount of heat generated at the weld interface, the amount of time that heat is applied and the clamping pressure. All of these factors can be user-controlled; however, it is the user's responsibility to determine the balance of these factors. For example: if a part is taking too long to reach adequate weld-collapse, burning of the plastic may result; this can be seen as tiny bubbles in the weld seam indicating plastic vaporization. In such a case, increasing the clamping pressure will help ensure collapse within the allotted time frame.

Weld flash
Weld flash (or *melt blow-out*) results from expanded, un-fused material that leaks from the weld seam, see letter J of Image 7 on page 8.

If weld flash is not acceptable for aesthetic or functional reasons, it is recommended that the following techniques be employed:

Melt covers can keep flash from escaping or entering the component where it is not wanted. Refer to letter "*H*" of image 7 for an example of this.

A melt blow-out reservoir is essentially a small gap designed along the weld seam with adequate room to collect the weld flash, letter "*K* of Image 8 on page 8.

Clamping Overview

Clamping pressure is necessary to ensure contact of the joining partners so conduction of energy from the absorptive partner to the transmissive partner can take place.

Also, as the polymers are excited by the laser energy, they will expand. If left un-clamped there will be no containment of the expanding polymers and fusion will not occur.

Each application will have customized clamp tooling. Clamping needs to be applied as close to the weld area as possible without obstructing the laser. 0.5 to 1.0mm should be allotted on both sides for clamp tooling (dependent on clamping method, see below).

Clamping pressure typically ranges from 2-4 MPa (~300-600psi). This pressure will be supported by lower component clamp tooling, often called *nests* or *workpiece holders*.

Nests/Bottom Clamp Tooling
Nests are custom designed to fit the component dimensions, providing support the entire length of the weld seam from the bottom.

Top Clamp Tooling
There are a few different types of clamp tooling, dependant on your application one may better than the next.

Transparent clamp tooling – a flat, clear piece of glass or acrylic which applies pressure to the entire top layer, see Image 4.

- Pros: simplest method, good for prototyping and small runs
- Cons: component surface must be entirely flat, tooling is easily contaminated by dust or particles which can result in burning of the component.

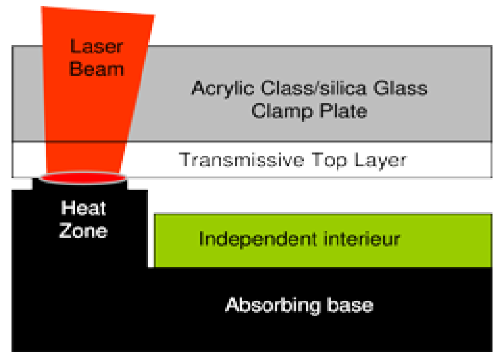


Image 4 – Transparent clamp tooling

Metal clamp tooling – metal tooling is created specific to the joint pattern, flanking the seam on each side. The tooling is attached to a transparent glass or acrylic piece where force is applied through it to the metal tooling, see Image 5.

- Pros: component can have 3D surface attributes, better clamping pressure at seam, metal tooling will last longer
- Cons: contamination of acrylic/glass is still possible, more complicated tooling

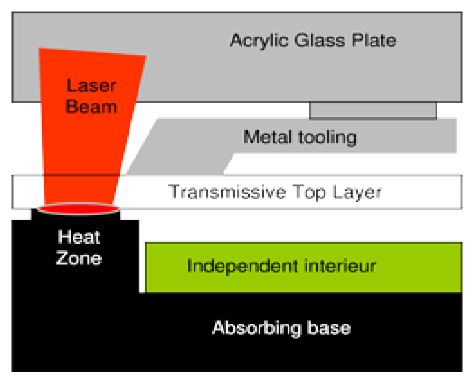


Image 5 – metal clamp tooling

Dual clamping device (all metal) – the dual clamping device provides clamping on both sides of the weld seam and requires no acrylic/glass piece, see Image 6.

- Pros: component can have 3D surface attributes, best clamping pressure at seam, metal tooling will last longer, no acrylic/glass means no contamination

- Cons: most complicated tooling design

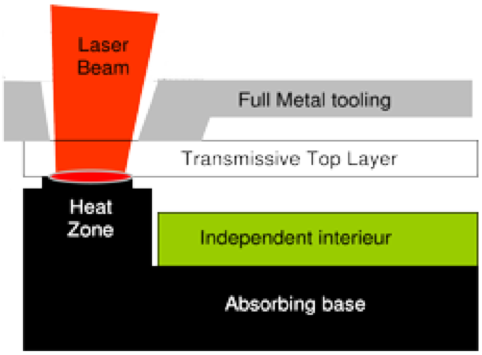


Image 6 – dual clamping device (all metal)

Other Clamping Considerations

It is recommended that measures be taken during the design and injection molding phase to ensure that warping is minimized and the joining parts fit together well, without gaps. If gaps are present, burns, or loss of energy can occur at the interface resulting in poor weld quality.

Centering lugs, although not required, are designed to mechanically ensure accurate alignment of the upper joining layer to the bottom joining layer.

A Basic Guide to Joint Types

Common Joint Types

Laser plastic welding deals with two main types of joints: lap joints and radial joints. There are many variations of each, but these are the two joints most commonly used in laser plastic welding.

Special Joint Characteristics

Image 7 is also a lap joint, but has added characteristics which enhance its design for the laser plastic welding process.

These characteristics (marked as letters A-N in the following images) are described in detail throughout this document; the legend on page 10 has references for each corresponding characteristic.

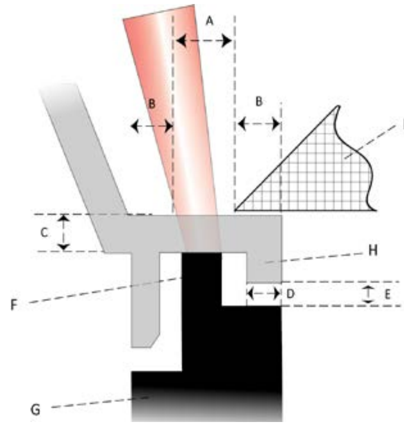


Image 7 – Pre-Collapse

Image 8 below, represents a joint prior to melt-collapse. The distance of collapse is represented by the letter *E.* Notice the un-collapsed raised rib (*F*) compared to the next image, Image 8, with a collapsed rib.

The image below shows a joint after melt-collapse has taken place. Notice the weld flash (*J*) from the compressed plastic.

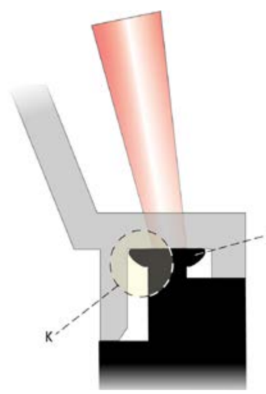


Image 8 – Post-Collapse

Radial Joint

Radial joints are used for cylindrical-shaped objects, such as joining tubing for catheters. Image 9, below, shows a pitcher with a welded lid, this weld process would have taken place similar to the example in *Image 11.*

Image 9 – Component with radial joint

When making radial welds, there are two methods: *fixed-part* or *fixed-laser.*

Fixed-part/moving laser – Image 10, below, is an example of a stationary (fixed) component, where the laser will move relative to the part tracing out the weld path.

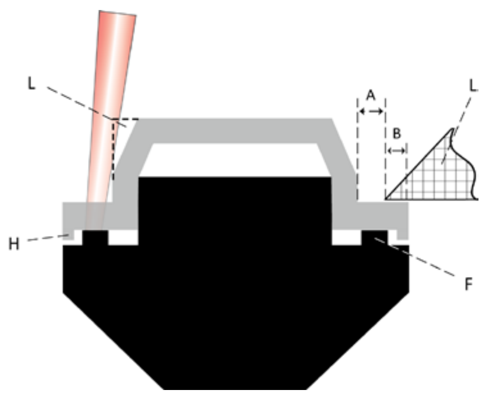


Image 10 – Fixed-part method

In this method clamping pressure is applied, top-down, using clamp tooling from the side of the joint, as in indicated by *I* in the image above.

This method is not ideal, because clamping pressure can not be produced on both sides of the weld seam, which is preferred, as it is blocked by the top layer's side wall. Also, the side wall will typically have to be tapered to allow the angled laser beam access to the joint, represented by the letter "*L*" in Image 10.

Fixed Laser/Moving Part (preferred) – in this method the stationary laser beam enters from the side, while the part is rotated.

Clamping pressure is not required, because the contact and pressure requirements are solved by "tapering" the two pieces so the transmissive layer is larger in diameter than the transparent layer. Like a sleeve, the transparent piece is forced onto the lower absorbing piece, the difference in size causes outward pressure. This is called a *press fit.*

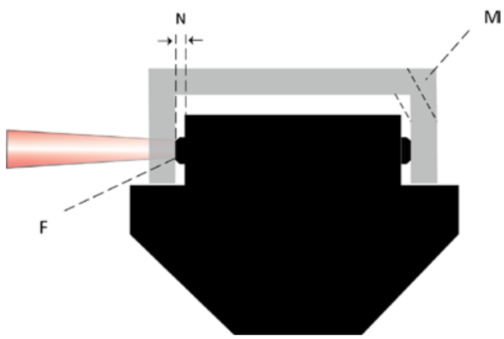


Image 11 – Fixed-laser method

Also, notice that tapered side-walls are not required, indicated by *M,* as the laser beam is entering from the side.

Please take into consideration the *press fit* collapse, labeled as "*N*" on Image 11 above. There is no difference between the press fit collapse and melt collapse other than the fact that the joint part design needs to ensure there is still outward pressure (created by size differences in the two parts) even after collapse has taken place.

Butt Joints
Butt joints, displayed in the image below, are not typically used in laser plastic welding. This is because the laser beam can not access the joint interface at the correct angle.

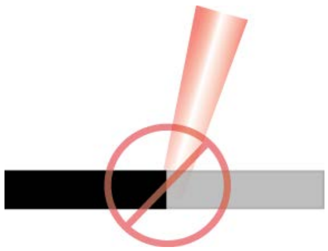


Image 12 – Butt joint

Joint Design Legend

Translucent Layer
Absorptive Layer

- A- Beam accessibility, p.5
- B- Clamp tool spacing, p.8
- C- Top layer depth
- D- Melt cover width
- E- Melt collapse
- F- Raised rib
- G- Mechanical limiting stops
- H- Melt cover
- I- Clamp tooling
- J- Weld flash
- K- Flash/melt blow-out zone
- L- Tapered side-wall
- M- Non-tapered side-wall
- N- Press fit collapse tolerance

Process Considerations

Special Shapes, Sizes and Applications
Laser plastic welding has great flexibility and fewer limitations as opposed to other plastic joining methods.

Below you will find some examples of extraordinary applications taken on by laser plastic welding.

3D and Contour Shapes
Laser welding opens up doors to complex component shapes, because of the precise control over the laser beam, applying energy only to the weld interface.

With typical laser welding processes the laser source has a fixed height above the component; height (z axis) changes of complex joints can not always be overcome because the laser beam's focal point will vary dependant as height changes.

The breakthrough TwinWeld 3D, robotic-arm-assisted welding system, moves the entire laser source in relation to the component. Height changes are not an issue, because the laser source moves at a constant height in relation to the weld joint regardless of z axis changes in the component.

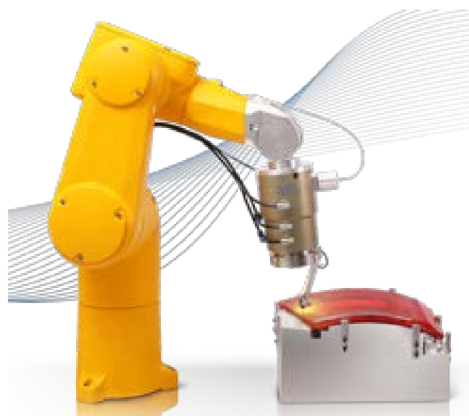


Image 13 – TwinWeld 3D system

Image 13, above, shows an example of a 3D weld, using the TwinWeld 3D robotic arm assisted system. Notice the pressure is applied via a roller-arm projecting from the head of robot. In this case pressure and energy are applied only where needed, eliminating the need for expensive upper dies.

Large Components
Again due to the TwinWeld 3D technology, large components can be welded easily. No longer restricted by a fixed laser source, which can scan only limited work areas, the TwinWeld work area

can be as large as the robotic arm is able to move, 1,200mm^2 (47in^2).

Small Components
The precise nature of laser movements and its ability to apply energy locally lends to the ability to weld very small components or component features, such as microfluidic devices.

Delicate Components
Until recently the only way to get a stress and particulate free joint for a delicate component, such as electronic sensors or microfluidic devices, was gluing and adhesives. Other methods cause too much heat, leave damaging/contaminating particulates or put too much stress on the delicate parts.

Laser welding solves all of these problems: heat is localized to the joint so it will not effect circuitry or delicate features, no particulates are created from the process to contaminate the component and part stress is reduced drastically as the only force applied to the component is the static force of the clamping unit.

Cycle Time Considerations
The following process flow example will give you an idea of common steps to consider when estimating cycle time for you project:

1. Workpiece loaded
2. Clamping pressure engaged
3. Laser on
4. Cooling
5. Clamping pressure disengaged
6. Workpiece released
7. Total Cycle Time

It is impossible to give a universal quote, regarding cycle times, as each application will have many variables which will affect cycle time.

Some variables to consider are: system type (manual/automated); the length of weld (longer welds require more heat to achieve acceptable collapse); cooling time (longer welds require more heat and in turn will take longer to cool).

Joint Testing and Inspection
An initial visual inspection of the weld seam should indicate a great deal. A good weld should be relatively consistent in width and color, and free of bubbles or voids.

A secondary test is a simple pull test. After ripping the layers apart, a good weld will be indicated by the presence of absorptive layer material on the transmission piece, consistently along the weld seam.

Testing for hermetic seals – testing for hermetic sealing can be done with a variety of methods. We suggest the following:

- Physical/visual inspection
- Burst pressure test
- Submersion/bubble testing

Consultation and Contact Information

Please remember that this document is only a guideline to help get designers and engineers started. Every application is sure to have variances from this document.

We highly recommend consulting an LPKF laser plastic welding expert at some point in your initial concept phase or to determine feasibility.

Still not sure if laser plastic welding is the answer for your application? We would love to help you find out. Contact us for consulting advice and information on sample/feasibility runs.

Please send inquiries to :

Josh Brown
Marketing Development Representative
jbrown@lpkfusa.com
Phone: 503.454.4231

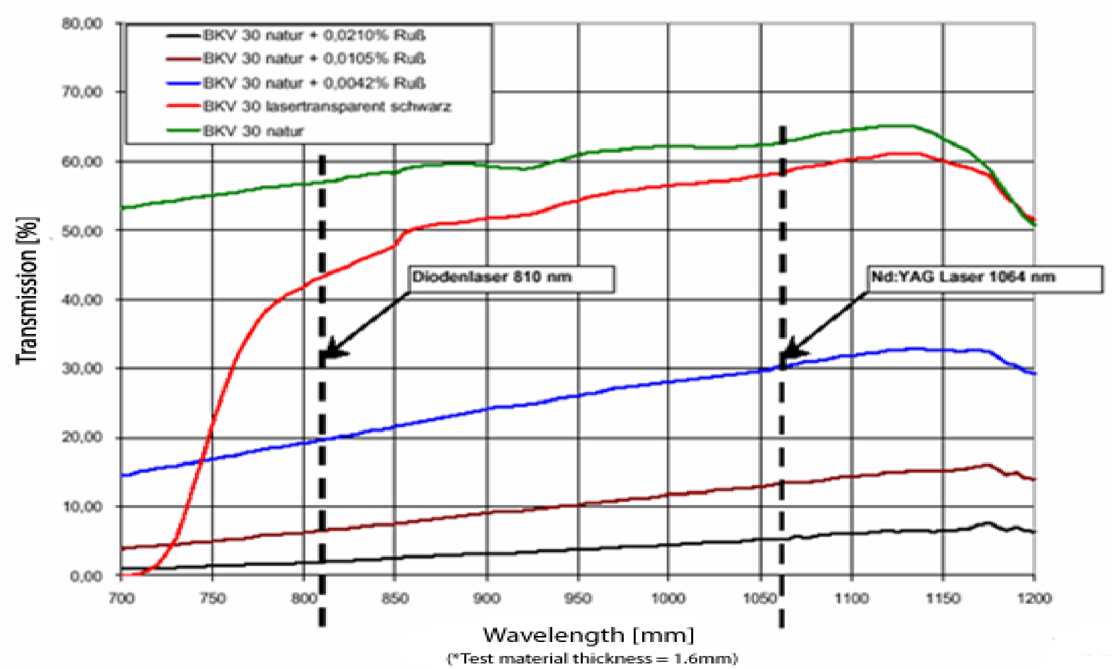
Here are a few details we recommend having available when you contact us:

- A basic summary of your application
- Materials
  - Types
  - Number of layers
  - Thickness
- Component details
  - Overall size
  - Weld length
- Desired cycle time
- Seal requirements
- Other requirements:
  - Strength
  - Optical
  - Function
  - Other
- What is your reason for considering laser plastic welding?

Appendix

Charts

Chart A.1 – Effects of Carbon Content on Laser Transparency



Source*: Welding Technologies presentation,* Frank Krause, Lanxess, 2005

Chart A.2 – Transmission Rate at Different Material Thicknesses (Material BKV 30 H2.0 9404/0)

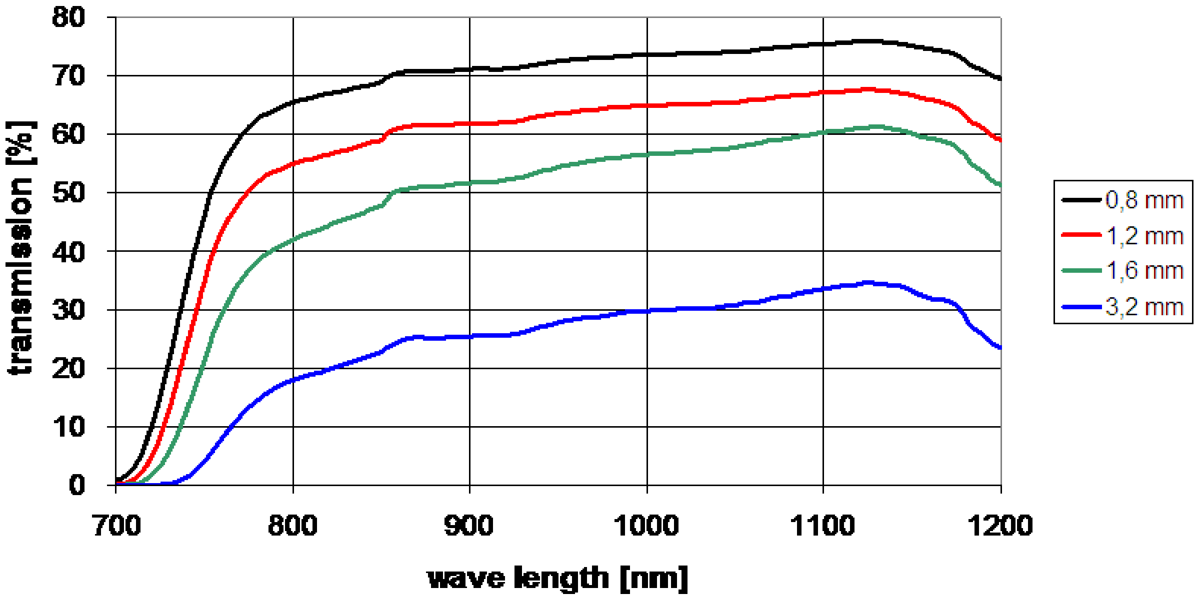


Table B.1 – Plastic Compatibility and Weld Quality Table

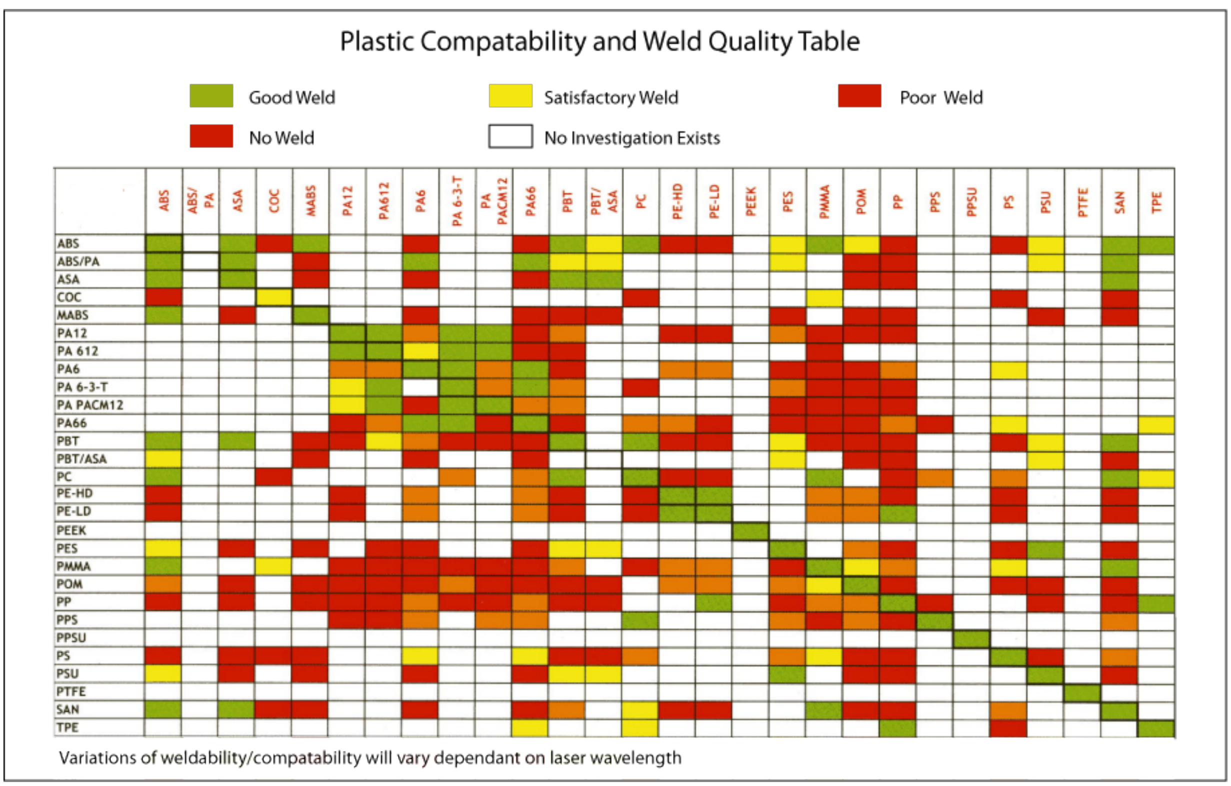


Table B.2 – Common Additives by Type and Brand with Contact Information

Additive - Company	**First Name**	**Work Phone #**	**Email**
Clearweld - Gentex	Lee Ann Spaulding	(570) 282-8648	lspaulding@gentexcorp.com
Laser Flare - Merck-EMD	Matthew Gailey	(912) 964-3062	matthew.gailey@emdchemicals.com
Pigmentations - Opticolor	Ronald Radmer	(714) 893-8839	rradmer@opticolorinc.com
Pigmentations - Orient	Keith T. Truzzolino	(908) 298-0990	keith@orient-usa.com

Table B.3 – Working Field by System, LPKF Laser & Electronics

System	**Metric (focus diameter)**	**English**
LQ-Vario	210 x 210mm	8” x 8”
	110 x 110 mm	4” x 4”
LQ-Power	45 x 45mm (.6mm)	1.8” x 1.8” (23.6 mils)
	110 x 110 mm (1.2mm)	4.3” x 4.3” at (47.2 mils)
	154 x 154mm (1.3mm)	6.1” x 6.1” at (51.2 mils)
LQ-Integration	45 x 45 mm	1.8” x 1.8”
	110 x 110 mm	4.3” x 4.3”
	154x 154 mm	6.1” x 6.1”
TwinWeld 3D	600 x 600mm	23” x 23”
	1,200 x 1,200mm	47” x 47”