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REVIEW OF LASER PLASTIC WELDING PROCESS

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ABSTRACT

Laser plastic welding requires one part to be transmissive to a laser beam and either the other part absorptive or a coating at the interface to be absorptive to the beam. The two parts are put under pressure while the laser beam moves along the joining line. The beam passes through the first part and is absorbed by the other one or the coating to generate enough heat to soften the interface creating a permanent weld. Semiconductor diode lasers are typically used in plastic welding. Wavelengths in the range of 808 nm to 980 nm can be used to join various plastic material combinations. Power levels from less than 1W to 100W are needed depending on the materials, thickness and desired process speed. Diode laser systems have the following advantages in joining of plastic materials:

- Cleaner than adhesive bonding
- No micro-nozzles to get clogged
- No liquid or fumes to affect surface finish
- No consumables
- Higher throughput
- Can access work-piece in challenging geometry
- High level of process control

Requirements for high strength joints include:

- Adequate transmission through upper layer
- Absorption by lower layer
- Material compatibility – wetting
- Good joint design – clamping pressure, joint area
- Lower power density

KEYWORDS: Laser Plastic Welding, Optically Transparent, Laser Absorbent Layer

INTRODUCTION

The laser equipment has been founded at the end of 2000 by employees of the Bavarian Laserzentrum gGmbH and offers customized solutions for laser-beam plastic welding by process development, job shop and production systems. As lead-investor the LPKF Laser & Electronics could be won, an international market leader in the field of laser-based production techniques for modern microelectronics.

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.

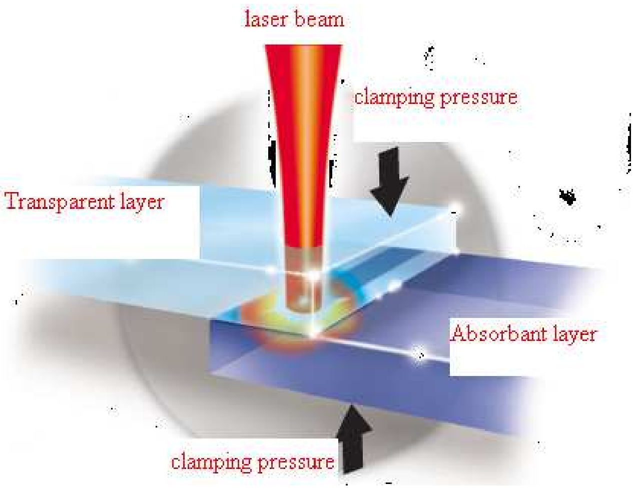

Figure 1: Laser Plastic Welding Process

BINDING TECHNOLOGY

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.

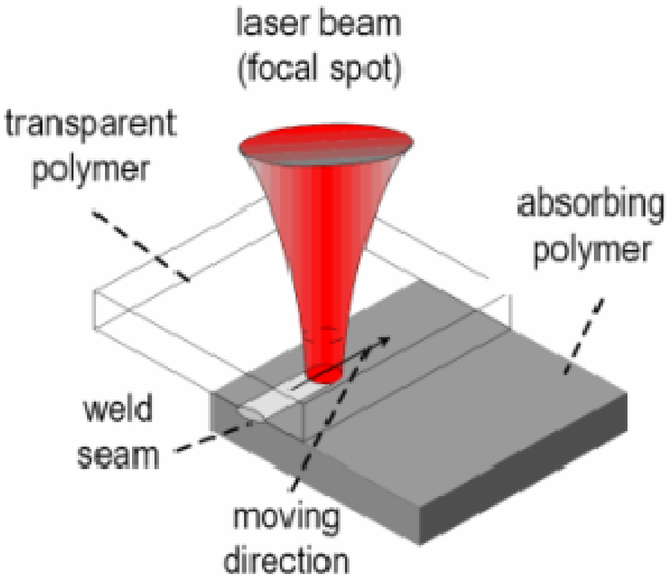

Figure 2: Principle of Transmission Welding

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 Clear weld, by the Centex 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 on for details.

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.

Table 1: Compatibility of Plastics

	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						+								+

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.

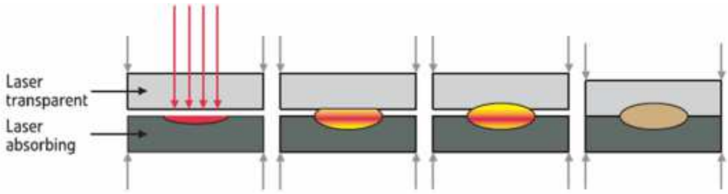

Figure 3: How Weld Joint Forms

PROCESS METHOD

This 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.

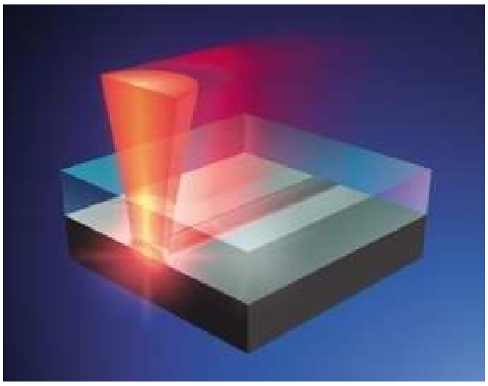

Figure 4: Contour Welding

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, Various.

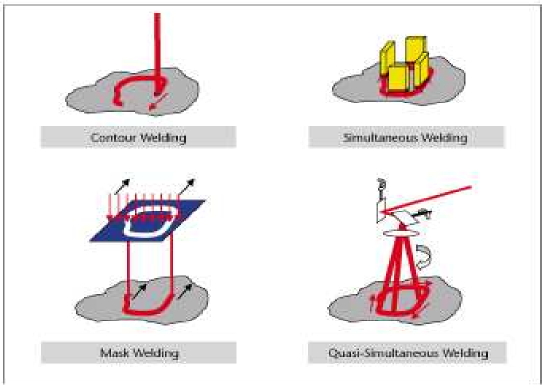

Figure 5: Welding Process

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

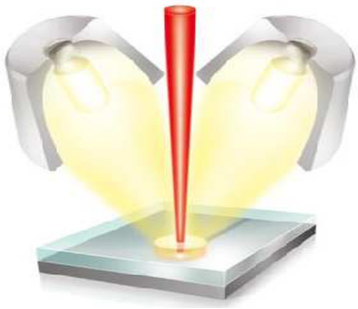

Figure 6: Hybrid Laser Plastic Welding

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.

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

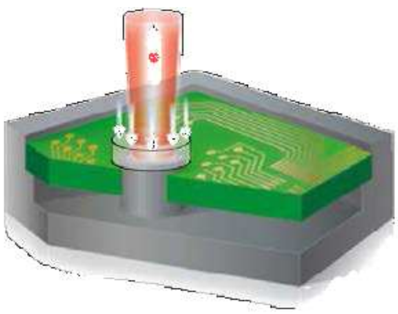

Figure 7: Laser Staking

PART DESIGN AND JOINT CONFIGURATION

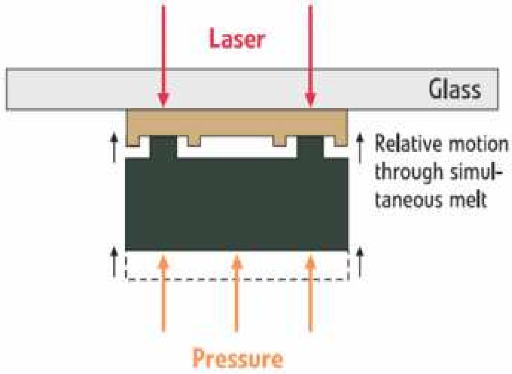

Figure 8: Part Design

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).

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.

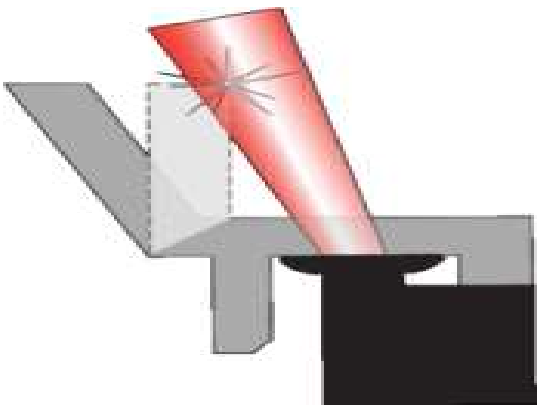

Figure 9: Beam Accessibility

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. Figure 10 shows a common lap joint prior to melt-collapse. 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.

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.

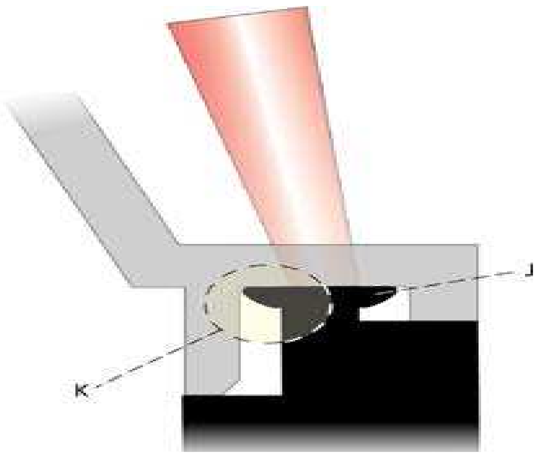

Figure 10: A Joint Prior to Melt-Collapse

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. 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. A melt blow-out reservoir is essentially a small gap designed along the weld seam with adequate room to collect the weld flash.

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 work piece 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 figure 8.

- **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.

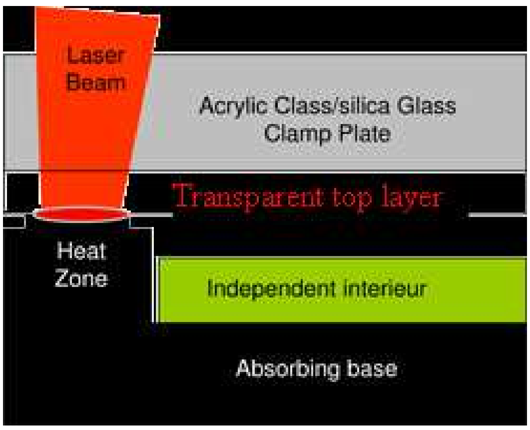

Figure 11: Transparent Clamp Tooling

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 below figure.

- **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.

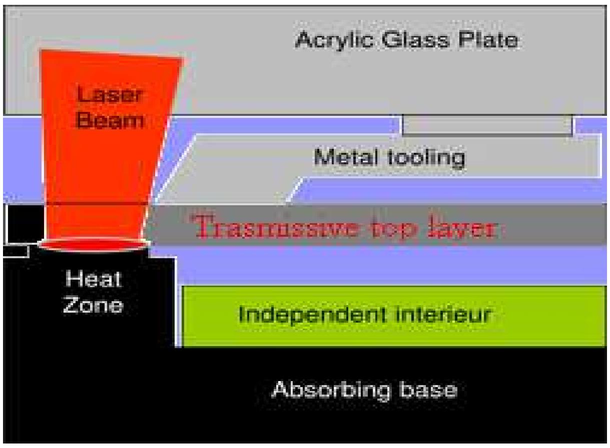

Figure 12: Metal Clamp Tooling

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 figure 13.

- **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.

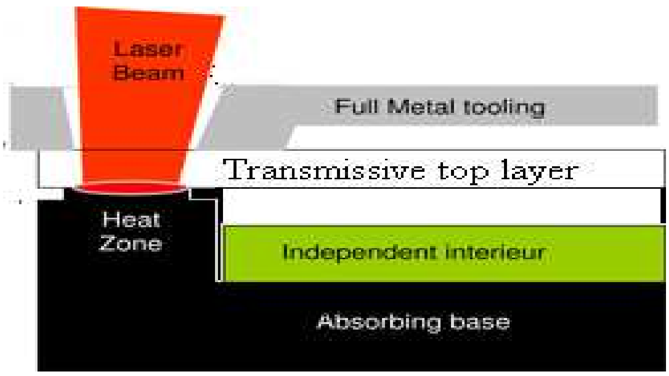

Figure 13: Dual Clamping Device (All Metal)

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.

PROCESS CONSIDERATION

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.

Figure 14: 3D Weld

Figure 14 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 (47in2).

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 micro fluidic 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 micro fluidic 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:

- Work piece loaded
- Clamping pressure engaged
- Laser on
- Cooling
- Clamping pressure disengaged
- Work piece released
- 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

Degree of Complexity

The colors of the materials involved determine the degree of the complexity of the process itself. Except for the welding of two transparent materials, all other material combinations are joined using a sandwich of a "laser-transparent" part on top of a "laser absorbent" part (Figure 1).

The laser is used to generate a melt pool in-between the interfaces. Due to the absorption time and the generation of the melt pool, as well as for the wetting process of the melt pool onto the transparent plastic, such a process needs a certain time frame and cannot be done infinite fast.

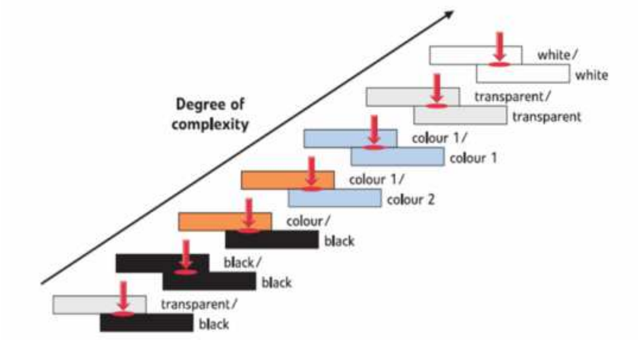

Figure 15: Degree of Complexity

PLASTIC JOINING AND PROCESS COMPARISON

Laser Plastic Welding

This process involves passing laser radiation through an upper laser transmissive layer where it is then absorbed at the surface of a lower absorptive layer, creating heat and a weld under clamping pressure.

Advantages

- Flexible – capable of welding complex, intricate, large and 3D part geometries.
- Process monitoring – multiple, sophisticated online process monitoring techniques allow for excellent quality control and fewer bad parts.
- Minimal part stress – well suited for sensitive applications.
- Low total cost of ownership – few failed parts, minimal system maintenance and no consumable required in process.

Disadvantages

- Initial capital investment – although systems have become much more affordable they tend to cost more than systems from competing methods.
- Tight part tolerances – process is not forgiving to poorly molded pieces.
- Special plastics characteristics required – due to the nature of the process plastics must have certain laser transmissive/absorptive properties (see LPKF's Design Guidelines Document for more information).

Applications and Industries

- Automotive – sensor housings, tail lights and manifolds.
- Medical – micro fluidic devices and catheters
- Consumer electronics – electric shaver face plate, make-up application brushes and digital display covers.

Ultrasonic Welding

Internal friction induced by ultrasonic oscillation melts the boundary surfaces of the joining partners. Fusion of the parts is reached by applying a certain pressure.

Advantages

- Very short cycle times – cycle times often under 5 seconds.
- Limited 3D contours – joints do not have to be completely flat.
- Low maintenance costs.

Disadvantages

- Flash– flash or excess melted plastic will likely protrude from joint.
- High mechanical load – resonance frequencies will exist throughout the entire part and can potentially effect/damage the part outside of weld zone.
- Particulate development – dust-like particles left behind that may cause part contamination

Notable Applications

- Mobile phone housings, bumper reinforcements and intake manifolds.

Hot Plate Welding

Joining partners are heated at joint by putting them in contact with a heated metal plate. Once molten the plate is removed and the pieces are fused under compression.

Advantages

- Cost – hot plate welding is a very inexpensive process as it requires no consumables, low equipment costs and part size is a non-issue.
- Handheld devices are possible – less complex applications can be bonded by handheld devices.

Disadvantages

- Simple part geometry required – simple contours are possible, but intricate designs are not.
- Flash – flash or excess melted plastic will protrude from joint.
- Tack – molten plastic may stick to hot plate.

Notable Applications

- Large profile applications, center consoles in automobiles, fishing buoys and glove box lids.

Parts are rubbed together, the friction created from this process generates heat at the contacting surfaces where the plastic becomes molten and weld able.

Advantages

- Cost – friction welding is an inexpensive process and the systems are priced competitively.
- Low maintenance – low maintenance means minimal downtown and cost savings.
- Low cycle times

Disadvantages

- Flash – large amount of flash generated, also dust-like particulates.
- High mechanical load – resonance frequencies will exist throughout the entire part and can potentially effect/damage the part outside of weld zone.
- Limited design freedom – only two-dimensional contours possible.
- Large weld line width – greater than 10mm in some cases.

Notable Applications

- Manifolds, housings, bumper reinforcements, pipes and large profiles.

High Frequency Welding

Oscillation of polar molecules is induced by an electrical field alternating with high frequency, which results in heating of the polymer.

Advantages

- Low thermal load – heating is localized to joint.
- No surface marring or damage – the process is touch less.
- Minimal flash – melt blow-out is minimized do to a small heat affected zone.

Disadvantages

- Expensive equipment – large capital investment for HF generator.
- Limited material choice – only polar polymers are weld able, PVC and PA.
- High protection regulations – electromagnetic radiation is produced from process.

Notable Applications

- Housings and any continuous welding applications.

CONCLUSIONS

Laser technology features numerous process-related advantages in comparison to conventional joining techniques, such as gluing, ultrasonic-, vibration- or (heating element) hot stamp welding. Most important here are flexibility and consistent quality of welds. The quality of a laser welding seam can usually compete with any conventional technology. Tensile shear force and pressure cycle tests show that a laser weld is at least as strong as a comparable ultrasonic welding seam. Moreover, laser welding does not generate any micro particles.

This is a significant advantage in particular for fluid reservoirs and medical components. As the laser applies the melting energy tightly localized, very compact structures with welding seams extremely close to heat-sensitive components can be realized. Also, there is no melt ejection and therefore no distortion with laser welding. Another advantage is, that only as much as needs to be welded, is actually heated.

Lasers work without contact and do not show any wear. The quality of the weld remains consistent and the component shows the corresponding quality. Moreover, the components do not have to be preprocessed before welding - this fact also contributes to a constant welding quality. It has been proven that the reject rate with laser welding can be reduced to a very attractive minimum compared to conventional technologies

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