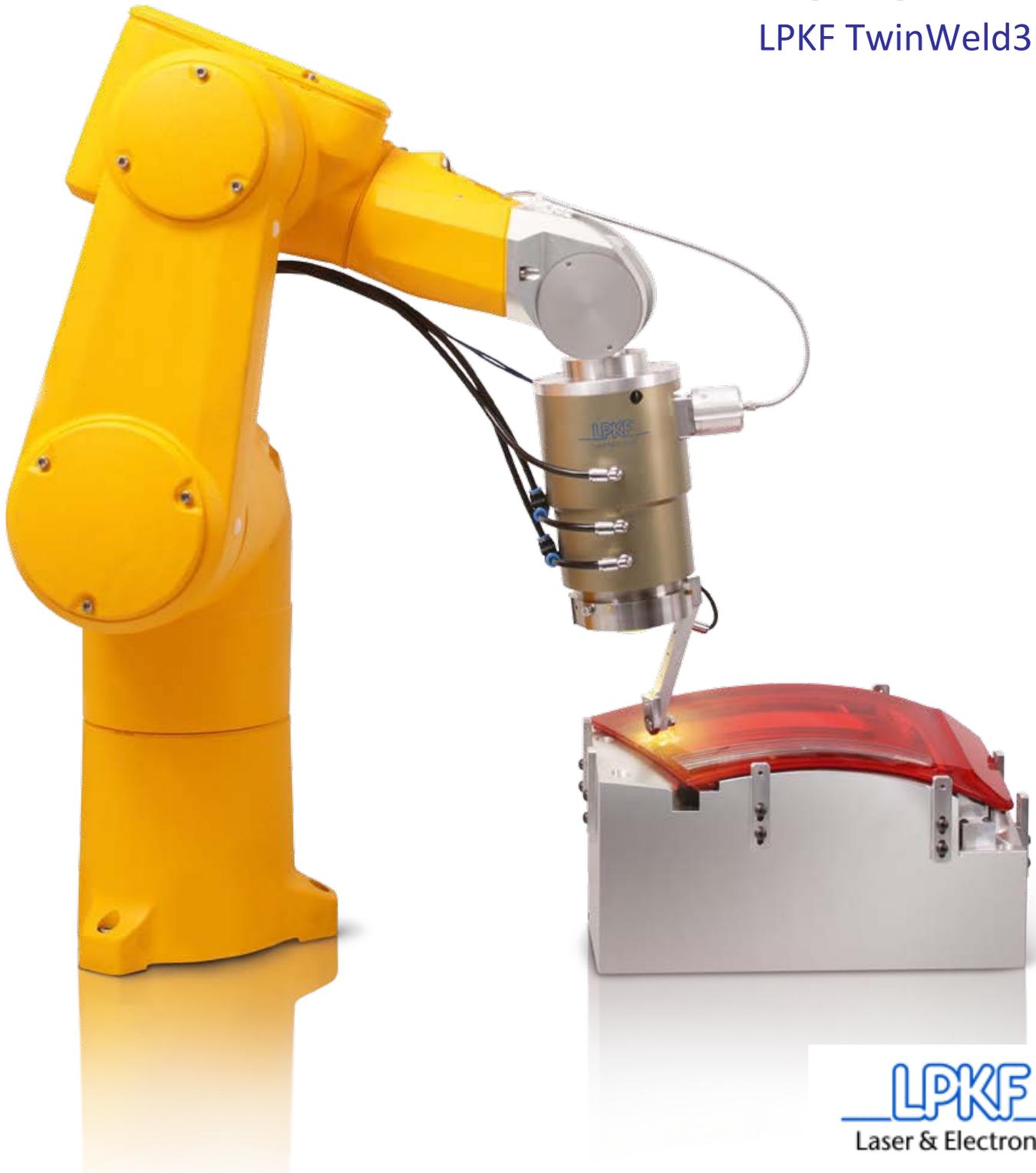


Design Guidelines: Hybrid Laser Welding Of Automotive Lighting with the LPKF TwinWeld3D



“ Thanks to the LPKF hybrid welding technique, SL Corp. has not only produced welding seams with previously unheard of quality, it also dramatically reduced the reject rate.”

-Simyun Sung, Manager SL Corp.

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Introduction

The purpose of this document is to outline the guidelines of laser hybrid welding, specifically in regards to exterior automotive lighting; giving designers and engineers the knowledge they require to navigate lighting development for laser hybrid welding during the concept and design phase.

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 Transmission Welding

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 the ability to weld complex and large parts.

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 radiation sources are outside of the visible light spectrum for the human eye. In fact, many 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: material type, additives (UV stabilizers, colorants and heat stabilizers), fillers (glass fiber, carbon fiber) and material 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, although not recommended. Ideally transmission rates should be 30% or greater. 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.

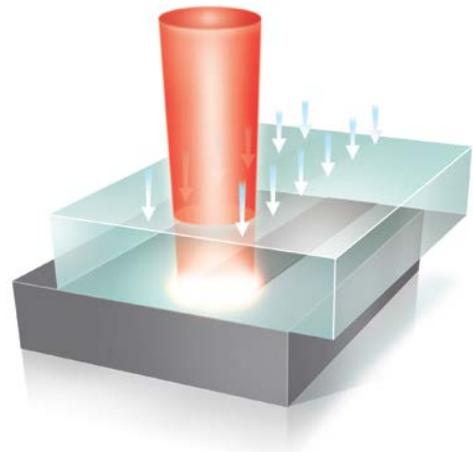


Figure 1 – Transmission Welding Principle

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, colorings and pigmentations are used. 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. Darker colors will absorb more effectively than lighter colors.

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.

Plastics specific to automotive lighting will be discussed in a later section.

| | 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 | | | | | | + | | | | | | | | + |

Figure 2 – Material Compatibility Chart

Table 1 below, outlines the miscibility of various plastics. A larger, more detailed list of compatible plastics, with bond qualities, can be found in figure 4 on page 6.

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 excellent contact along the weld joint. Contact and clamping will be discussed later.

Processes

There are four major laser welding processes methods: contour welding, simultaneous welding, quasi-simultaneous welding and hybrid welding. Each method has its specific advantages and disadvantages. Which method is practical depends on the application and the welding parts.

As a producer of laser welding machines LPKF Laser & Electronics offers machines for contour welding, quasi-simultaneous welding and hybrid welding. This document is focused strictly on hybrid welding using the LPKF TwinWeld3D.

Hybrid Welding

Hybrid welding is an advancement of the contour welding process. Hybrid welding employs the use of a powerful halogen lamp to assist the laser in the welding of the plastic. The polychromatic radiation of the halogen lamp has a larger focus, allowing for heating all around the weld joint.

The polychromatic radiation from the halogen lamp allows for volumetric heating of both the lens and lamp housing. This volumetric heating has a few clear advantages over regular contour welding.

Gap bridging - better gap bridging is realized as the halogen radiation heats the lens and housing simultaneously, softening the plastics and allowing for a better fit under clamping pressure.

Reduced stress - gradual heating and cooling of the plastics reduces stress and removes the need for the time-intensive post-weld annealing process required by other welding methods.

Faster welding speeds - “pre-heating” within the halogen thermal field allows for faster weld travel speeds as the plastic requires less energy from the laser to reach its melting point. Without hybrid welding, increasing the travel speed of the laser will reduce the tensile strength of the bond. Typical contour welding without hybrid technology is limited to about 20 millimeters per second to achieve desired tensile strengths, where hybrid welding can achieve 60 millimeters per second or more, see figure 13 on page 10.

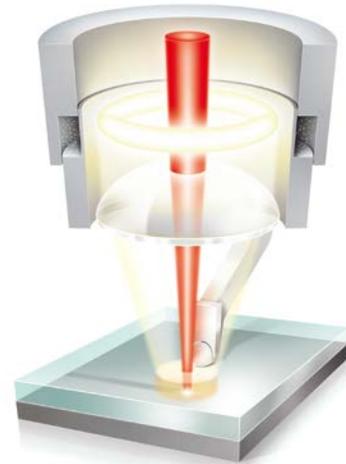


Figure 3 – Hybrid Welding

TwinWeld3D

The LPKF TwinWeld3D is a flexible, robotic arm-guided laser welding unit. The 6-axis robot allows for welding of any shape or contour with size limited only by the reach of the robotic arm.



Figure 4 – LPKF TwinWeld3D

The tightly packaged welding head contains the lenses for the laser as well as the halogen lamp, which allow for precise control of both forms of radiation. The welding head also provides the means for clamping. Affixed with a roller arm, clamping pressure is transferred from the robot through the arm.

Material compatibility

In order to achieve a bond the two polymers which are to be joined must possess a similar chemical makeup as well as have similar melting temperatures.

Figure 5, displays the known, weldable thermoplastics in reference to the other plastics which they are weldable to. In the majority of automotive lighting applications the most common plastics are:

- Headlights – PC (lens) to PP (housing)
- Tail Lights – PMM (lens) to ABS (housing)

The chart has been highlighted to reflect these plastics. It is important to note that polycarbonate (PC) is not typically weldable to polypropylene (PP) as the heat extension coefficient and surface energy of PP differs greatly from most other polymers. However, laser plastic welding, unlike other welding methods, is able to weld PC to PP.

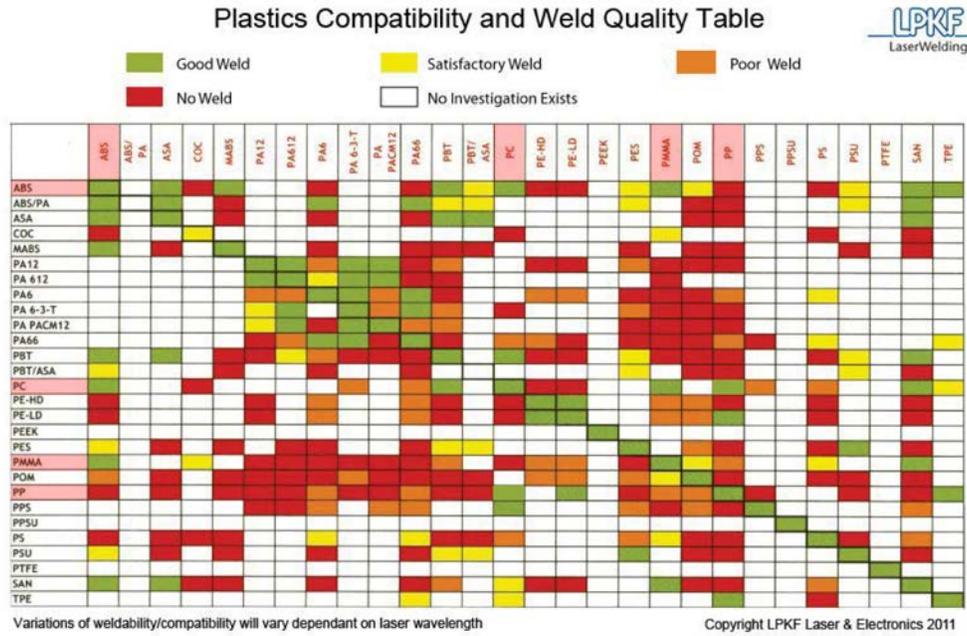


Figure 5 – Material Compatibility Chart

Figure 6 displays the melting/softening and decomposition ranges of typical thermoplastics. As stated previously the two joining plastics must have similar melting temperatures.

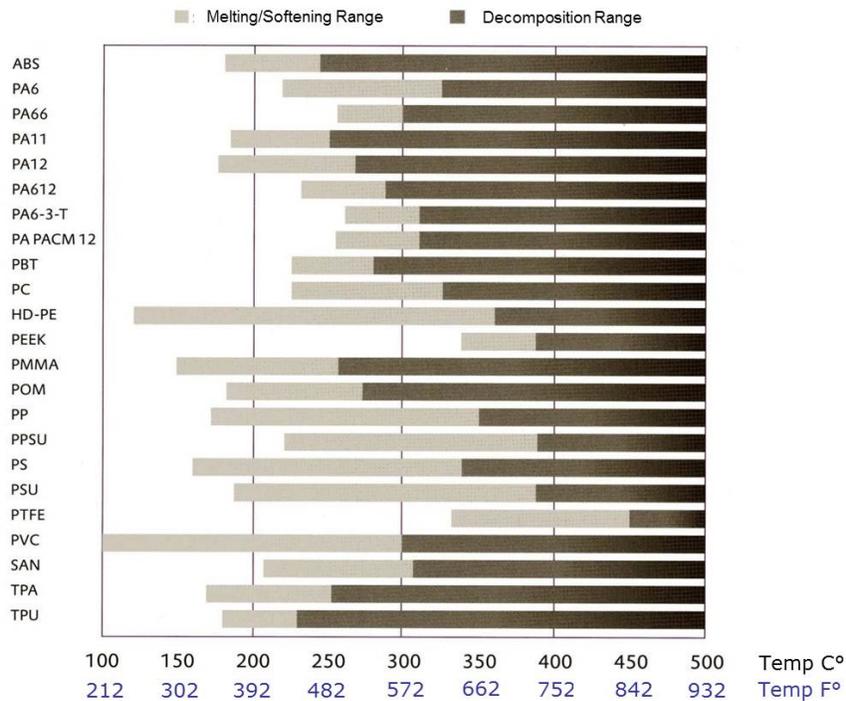


Figure 6 – Melting and Softening Ranges

Clamping and Contact

Laser plastic welding requires both parts to be in contact throughout the entire weld seam. If there is a gap at one point in the weld seam heat will not be able to transfer from the lower layer to the upper layer; the upper layer will not melt and the result is an area with no weld.

Gaps are typically caused by imperfect and varying geometries from the molded plastic. Clamping force is used to ensure that the joining partners are in contact during the welding process. In hybrid welding the clamping force is provided via a roller-arm attached to the welding head, see image 7.

Although clamping force can overcome geometrical tolerances to ensure contact, it is recommended that parts be molded to high standards, ensuring a proper fit and good contact despite.

Nest

A custom nest or workpiece holder provides the necessary support of the joint from underneath. Besides providing support the nest also helps to accurately position the lamp as it is placed for welding.

Joint designs will often include a locating/positional rib below the joint, on the housing to ensure that the joint position is maintained during the influence of heat and pressure of the process.

Roller Accessibility

Z-axis height changes are easily overcome by the flexibility of the robotic; however the roller arm does introduce one limitation in height changes. A height change too close the joint can result in an obstruction to the roller-arm, this is best displayed by figure 8 below.



Figure 7 – TwinWeld3D with Nest

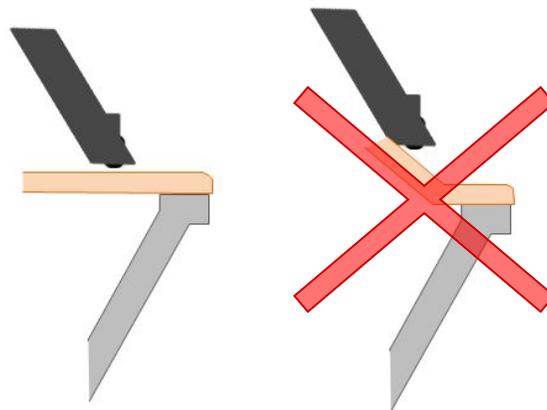


Figure 8 – Roller-arm Accessibility

Joint Design

Welding Rib

Welding ribs, also called collapse ribs, are designed into the majority of laser plastic welding applications. The rib, designed into the lower layer or housing in the case of automotive lighting, is the focus of the laser beam. The purpose of the collapse rib is to overcome dimensional tolerances in the parts.

Heated by the laser to its melting point, under clamping pressure the rib will collapse and the upper layer will “travel” towards the lower layer, represented by A in figure 9. A collapse of 0.2mm to 0.5mm is recommended. The travel ensures tolerances, that may cause gapping, are overcome.

The weld rib should be designed specifically to each application, but common dimensions are roughly 2mm to 3mm in width (accounting for beam spot size and tolerances), represented as B in figure 9. A 0.2mm to 0.5mm height is recommended for the collapse rib to ensure adequate collapse can be realized.

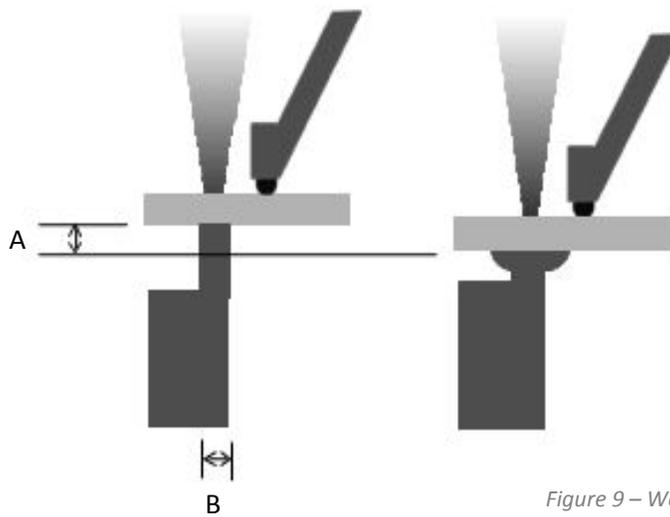


Figure 9 – Welding Rib

Seam Width and Placement

The actual seam width can vary based on the laser beam spot size and should be coordinated to the application, taking into account strength requirements and design. TwinWeld3D systems are capable of producing spot sizes from 1.5mm to 4mm in diameter.

As laser plastic welding produces very tight and consistent weld seams with minimal flash the weld seam can be placed virtually flush to the outside of the part.

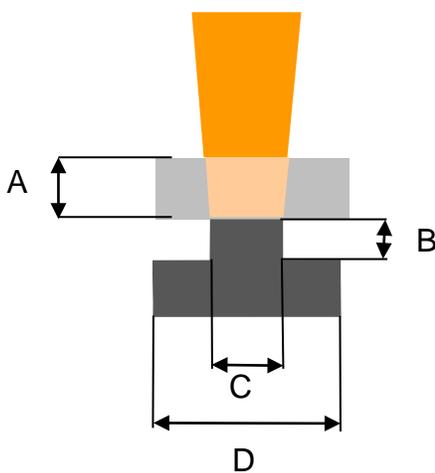


Figure 10 – Common Joint Dimensions

Lens Layer Thickness

On one hand the laser transparent material has to be thin enough to transmit an adequate amount of radiation to the housing; the thicker the lens the less energy transmitted. On the other hand the lens needs be thick enough that it can physically transfer the necessary clamping pressure from the roller-arm to the housing. Thinner materials will see buckling and breaking.

Typical thicknesses range from 0.8mm to 3mm dependent on the material in use, see letter A in figure 10. It is perfectly possible to achieve higher or lower values depending on material combinations.

Housing Layer Width

The housing layer also needs to be able to support the clamping pressure without buckling. A general guideline to abide by is to design the housing wall width to be the thickness of the welding rib (commonly 2mm to 3mm) plus an additional 1mm, see letter *D* in figure 10.

Housing Layer Reinforcements

To add further protection against sidewall buckling in the housing, support stiffeners should be designed into the part, show in figure 11.

Vertical Steps

Vertical steps should be avoided within the joint. Steps cause clamping problems; sufficient clamp force cannot be produced uniformly on the step and improper contact can result.

If steps must exist it is encouraged to use larger radiuses to help evenly distribute the clamp force through the whole step. In figure 12, the red, dashed line is an example of an extreme step; the proper design would have a larger radius as displayed by the black contour.

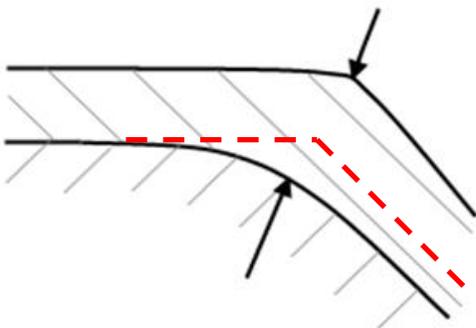


Figure 12 – Vertical Steps and Radiuses

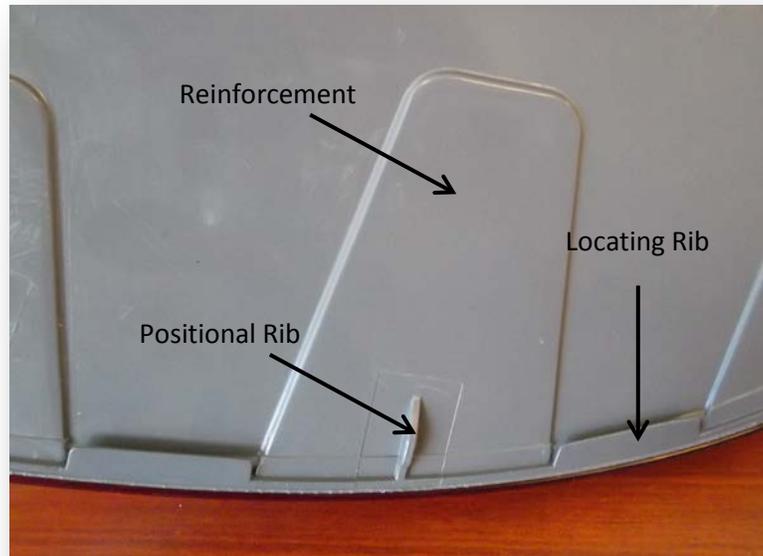


Figure 11 – Reinforcements, Locating Ribs and Center Ribs

If angles are still too extreme then additional clamping devices can be used to ensure proper clamping. Dependent on the application the additional clamping devices may be located on the outside of the weld seam. In this case sufficient room between the weld joint and the edge of the assembly should be realized. The minimum supporting surface should be 1mm between the joint and the assembly edge.

If the joint is to be flush with the edge, dynamic clamping devices can be programmed into the travel of the robot to engage before and after the welding head has passed.

Centering Lugs

Accurate positioning of the lens to the housing and the housing to the nest is paramount. In order to simplify the clamping technology and to ensure dimensional accuracy, corresponding centering points should be planned for the joining partners. Positional ribs on the housing can ensure accurate placement as the part sits within the nest, see figure 11. Also, centering lugs built into the parts will ensure proper placement of the lens as it is mounted to the housing prior to welding.

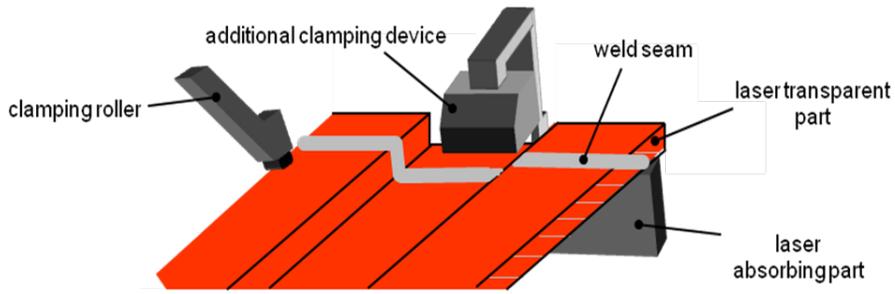


Figure 12 – Steps and Additional Clamping

Cycle Time

Cycle times will vary based on a variety of factors including material types, additives, contour length and geometric complexities. A good average figure for a total weld cycle for an automotive lamp is 30 seconds. Please keep in mind this is the welding time only and does not include loading or unloading of the part. Factors to consider for cycle time:

- Parts loaded into nest
- Indexing of nest fixture
- Robot moves to joint
- Laser on/welding begins
- Laser off
- Indexing of nest fixture
- Unloading

Travel Speeds

A preliminary cycle times can be calculated by multiplying the length of the weld contour by the laser travel, or scan, speed. Typical travel speeds for laser hybrid welding are 30 and 60 mm/s, with most application typically achieving the higher of the two figures.

In normal contour welding, increasing of scan speed will result in a reduced tensile strength in the joint. Hybrid welding however is capable of achieving faster scan speeds while retaining a high tensile strength, a factor of great importance to the durability of automotive lamps.

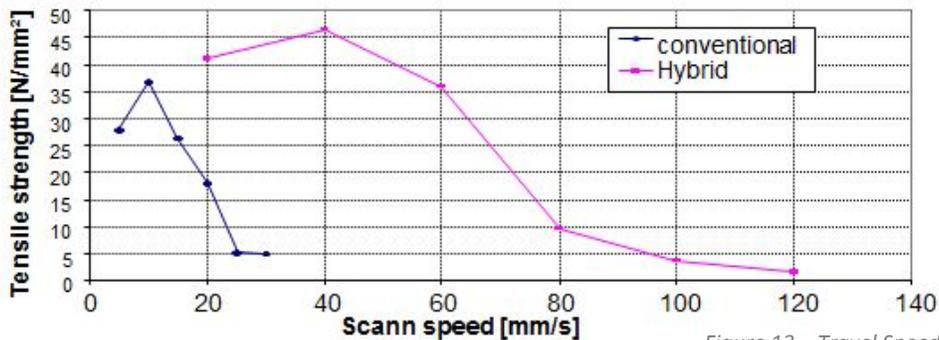


Figure 13 – Travel Speed v. Tensile Strength

The graph below displays the tensile strength of hybrid welding at various scan speeds compared to regular contour welding. This test was done on 2mm thick polycarbonate.

No Annealing Process

Automotive lamps are subject to large amounts of stress during both molding and also during welding, in methods other than hybrid laser welding. If stress is not addressed, over time warping and deformation can occur, often resulting in leaks at the weld sea. The post-weld annealing process involves holding the lamps in a heated chamber allowing the plastics to soften and relieve stress. This step can take hours and should be considered when comparing total cycle times between welding methods.

Laser hybrid welding, unlike other welding methods, requires no post weld annealing process. The halogen radiation softens and relieves the stress within the lamp during the welding process, alleviating the need for a time-consuming annealing step after welding.

Process Monitoring

The TwinWeld3D system comes with optional process monitoring options to help ensure quality and reduce reject rates. Although laser welding has a variety of quality control techniques at its disposal, automotive lighting applications typically take advantage of either *reflection diagnosis* or *collapse monitoring*.

Reflection Diagnosis

Reflection diagnosis is a patented LPKF technique. The principle behind the technique is that as the part is illuminated by the laser radiation some of this radiation will be reflected. During the welding process the spacing between the two parts disappears and reflection will only occur at the surface of the upper part. Zones in the weld seam that have gaps will be identified by an identifiable second peak in measured reflection.

This system is capable of identifying leaks smaller than a human hair or 0.003", which entirely removes the need for leak testing upon completion of the weld.

Collapse Control

As stated earlier, collapse monitoring is used to ensure that geometric variances in parts are overcome by creating a collapse greater than the tolerances of the molded parts, ensuring no gaps and a consistent weld. The STU monitoring system developed by LPKF measures the height of the parts during the welding process. Melt collapse parameters are programmed into the system and if the measuring system detects discrepancies the system can make real time adjustments to compensate.

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 hybrid laser 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.

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