

# New Possibilities in Laser Plastic Welding through Absorbing-to-Absorbing (ATA)

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## 1. Abstract

Established plastic welding processes are facing a multitude of challenges due to growing customer requirements, which are blocking access to promising market segments. One of these processes is laser transmission welding, which offers unique advantages but has limitations in terms of the optical requirements for the joining partners [1]. The ATA process is a promising technology for overcoming these limitations. LPKF demonstrates this technology with its crucial aspects and highlights its unique advantages and extensive range of potential applications.

## 2. State of the Art

In laser transmission welding, two plastics with different optical properties are joined together under laser irradiation. The top layer, which faces the laser beam, requires a certain level of transmission to allow the laser beams to pass through sufficiently. These are absorbed by the underlying joining partner. The energy released in this process is converted into heat, which melts both the absorbing and the transparent joining partners via heat conduction. Both joining partners are in - contact throughout and are subjected to a continuous joining force, which is maintained after irradiation for the duration of the solidification process [2].

Laser welding in general offers several advantages [3]:

1. **Precision:** The energy input is applied exclusively to the desired areas, ensuring a gentle process that reduces the risk of damage to sensitive internal components such as sensors, membranes, or PCBs.
2. **Flexibility:** Scanner-based systems enable easy adaptation of the process to new or evolving components. If the welding contour changes, it can be easily adjusted by teaching the software. This results in particularly short setup times. In addition, sequential changes to the laser speed allow local adjustment of the energy input. This compensates for local hot or cold spots and ensures uniform energy input across the entire weld seam contour.
3. **Cleanliness:** No additional operating materials are introduced and there is no contamination of the components by particle formation during the process. By

selecting -suitable irradiation parameters, -degeneration of the polymers can be -prevented.

The challenges associated with laser transmission welding mainly focus on the optical properties of the transparent joining partner. Its transmission depends not only on the basic choice of material, but also on the fillers it contains and its thickness. If the transmission falls below the minimum of 20% recommended by LPKF, there is an increased risk of absorbing too much laser energy in the top layer and causing thermal damage without creating a joint. In laser transmission welding, this means that components are subject to strict - guidelines- regarding design freedom and polymer selection.

A comprehensive review shows that other joining processes for plastics are also subject to severe restrictions. While mechanical processes such as friction or ultrasonic welding struggle with particle formation and high mechanical stress for electronic components, other thermal joining methods such as hot gas or infrared welding involve high tooling costs, slow cycle times, and high energy consumption, which runs counter to increasing sustainability requirements.

For this reason, there is a growing need in the market for a technology that offers the advantages of laser welding without the limitations of a transparent top layer. To meet this need, LPKF has driven forward the development of the ATA process, which offers a new aspect of laser welding and opens up a wide range of applications.

In this variant of laser welding, both joining partners are irradiated separately from each other, see Figure 1, then brought into contact within a very short changeover time (typically < 1.5 s) and subjected to an appropriate joining force. This process is therefore similar to other sequential welding processes, such as hot gas or infrared welding, but differs from them in its precise and flexible irradiation strategy. This means that both joining partners are made of absorbing materials. The elimination of the transparent joining partner -thus removes the biggest limitation to laser welding to date and opens the door to a wide range of different applications.

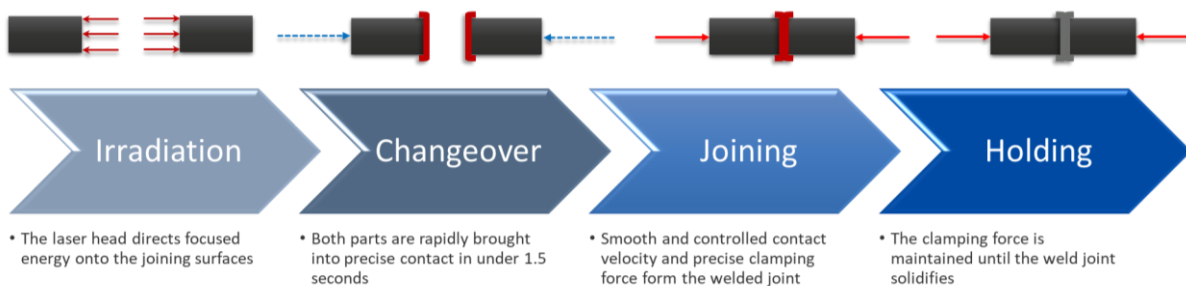


Figure 1: Process steps of the ATA process

### 3. Overcoming the limitations of laser welding

The elimination of restrictions mentioned in chapter 2 means that many applications can now also benefit from the unique advantages of laser welding. The following section lists the main restrictions that existed up to now and highlights the corresponding new possibilities.

1. **Expansion of the material portfolio:** High-performance plastics such as PPS or PEEK, with their elevated degree of crystallinity, pose a major challenge for laser transmission welding, as their low transmission means they can only be welded when the wall thickness is extremely thin. Using ATA, these materials can now also be joined using laser welding, with no limitations in terms of wall thickness.
2. **Freedom of geometric design:** Even plastics with high transmission can cause problems for laser transmission welding if the wall thickness is high or the top layer is heavily 3D- shaped in the welding area. This leads to strict design guidelines and limits the degree of design freedom for components. By directly irradiating both joining surfaces, there are no obstacles in the beam path, which greatly reduces geometric limitations and allows the separation plane of both joining partners to be freely selected.
3. **Functional enhancement through the addition of fillers:** Industrial applications increasingly require plastics with additional properties such as flame retardancy, electrical conductivity, or increased strength through the addition of glass fibers. Since the fillers required for this reduce the transmission of the plastic, this poses a major obstacle to laser transmission welding. However, this is not an obstacle for the ATA process, as the top layer does not need to be penetrated.
4. **Color component design:** Laser welding is particularly suitable for components that are subject to high aesthetic requirements. The coloration is decisive for both transmission and absorption. Accordingly, joining of color-matched components is difficult using laser transmission welding. Furthermore, it has not yet been possible to weld joining partners that are identical in color even under different lighting conditions (metamerism). With the addition of a suitable NIR absorber, the ATA process can now be used to join not only plastics of the same color, but also white plastics.

## 4. Crucial aspects for the ATA procedure

LPKF revives an old technology with a new concept. Although the concept of direct laser welding is nothing fundamentally new, LPKF stands out from the competition with its outstanding knowledge about the crucial aspects of the ATA-process.

### 4.1. Material selection and suitable carbon black content

When investigating new possibilities, it is important to find out which plastics can be welded using ATA. Table 1 provides an overview of the most common material requests that LPKF can successfully weld.

Material
PBT
POM-C
PPS
PA6
PA6.6
PP
ABS
LCP
PPA
PK

*Table 1: List of successful welded material by LPKF*

It is possible to weld nearly all plastics with an identical joining partner. Extensive material testing shows that challenges arise for the welding process when the carbon black content is too high ( $CB \gg 1\%$ ). This is noticeable in the low collapse achieved, even with relatively high energy inputs into the welding zone [4], [5].

In order to better understand the influence of carbon black content on the ATA welding process, experiments on test plates made of PA6.6 with varying carbon black content are carried out. In this series of experiments, variants with increasing carbon black content between 0.05% and 1.00% are tested with increasing energy input. The test parameters are carried over between batches. This shows that the collapse increases with energy input, but almost identical collapse is achieved for all variants, see Figure 2. For one batch, there is little change in component strength despite the change in collapse, which in turn indicates a generous process window, see Figure 3. It is noticeable that particularly high strengths are achieved for batches with low carbon black contents (CB 1 & CB 2).

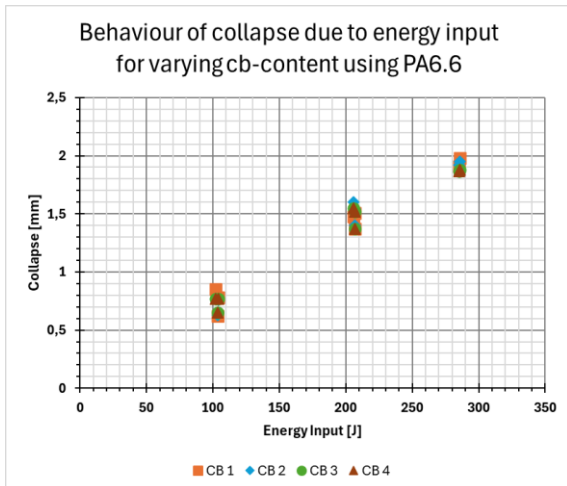


Figure 2: collapse via energy input for PA6.6 with varying cb-content

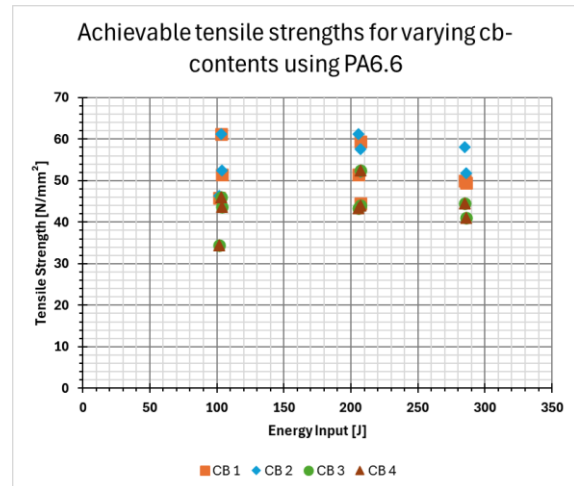


Figure 3: tensile strength via energy input for PA6.6 with varying cb-content

The tests conducted by LPKF identify the carbon black content of plastics as a decisive factor influencing the success of ATA welding. In addition, the behavior of common carbon black contents of CB 0.05%–1.00% and their influence on settlement and strength can be characterized.

## 4.2. Minimizing changeover time

Unlike laser transmission welding, the ATA process is a two-stage process. The heating and joining steps do not take place simultaneously, but one after the other. Therefore components cool down during the movement to the joining position. With a correspondingly long changeover time, this can lead to reduced strength or even no joint at all, while still achieving promising results in collapse, see Figure 4.

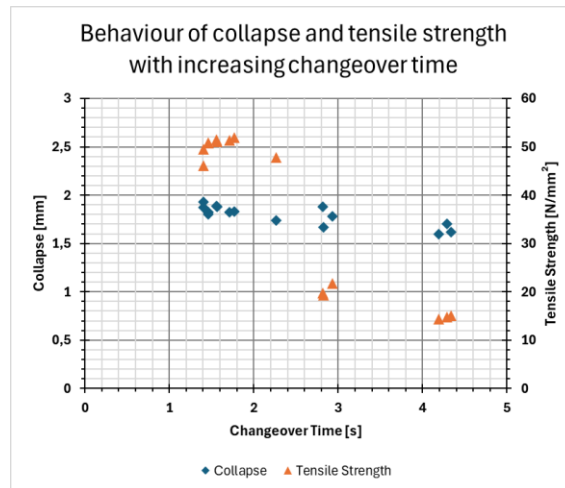


Figure 4: collapse and tensile strength via changeover time for PBT

Therefore, a sufficiently fast changeover time must be ensured. To achieve this, LPKF has developed a corresponding mechanical concept that meets the requirements of a highly dynamic system and can also be easily scaled to components of different sizes. Two linear axes move the joining partners independently of each other, allowing separate irradiation of the cover and housing; see Figure 5.

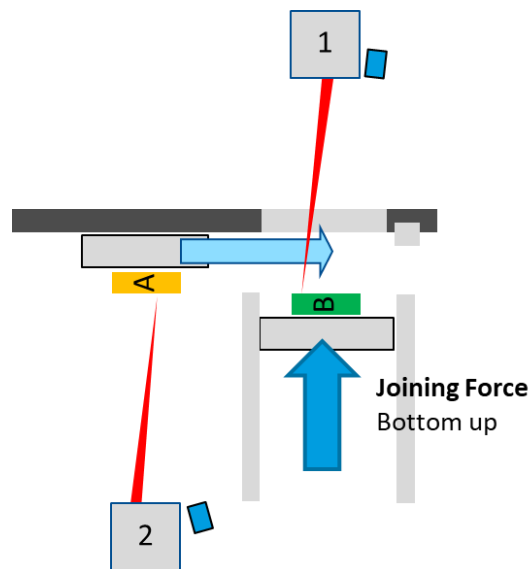


Figure 5: schematic representation of the mechanical concept for ATA from LPKF

### 4.3. Analysis tools for determining weld quality

To better understand the characteristics of welded parts via ATA, it is inevitably to further analyze the welded parts. LPKF's many years of experience in the field of laser welding technology is particularly evident in combination with its unique analysis capabilities.

LPKF draws on a wide range of tools to optimize applications not only during setup, but also continuously throughout the series production process.

**Thin-cut analysis for offline process optimization**

To detect sources of error in the weld seam, LPKF offers appropriate tools for making thin sections in its laboratories. Here, 10-50 µm thick cross-sections of the weld seam are examined and evaluated under a transmitted light microscope. This allows sources of error such as cavities or burnt material in the joint zone, uneven weld lenses, and inhomogeneous glass fiber distribution in reinforced plastics to be identified. These findings enable appropriate measures to be taken to achieve optimal results.

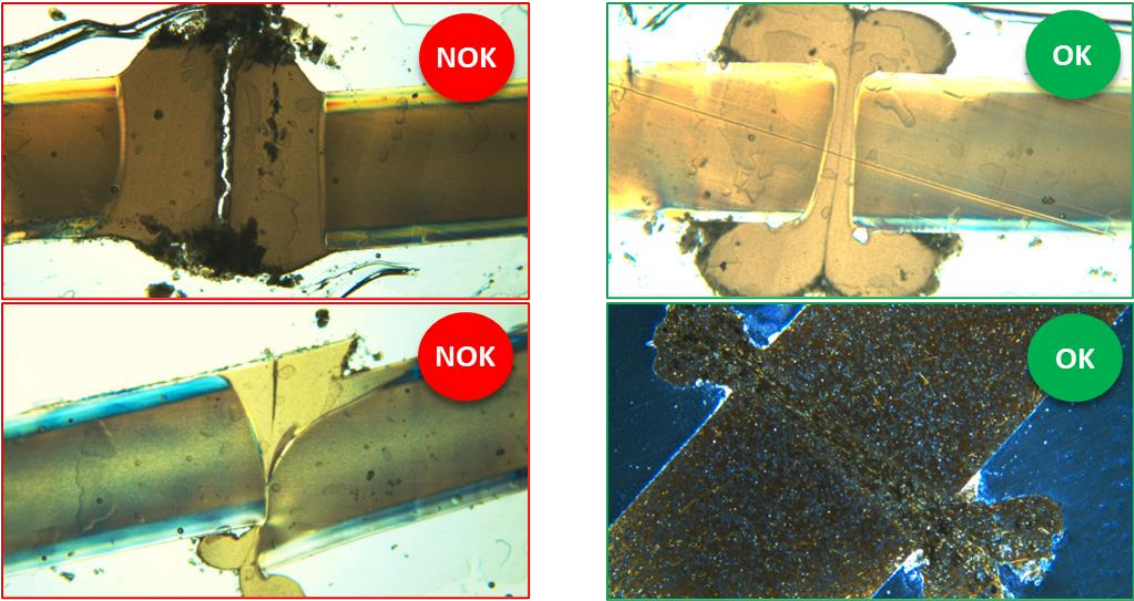


Figure 6: comparison of OK and NOK weld seams in thin sections

### Thermography for inline quality control (TherMoPro)

With TherMoPro, LPKF has been offering the best-in-class solution for thermographic quality control of laser-welded plastics for five years. This solution captures a thermal image of the welded component, providing insight into its heat distribution. Based on the definition of an ideally welded reference component, a traceable statistical evaluation is performed for each welded component. In addition to the temperature distribution, the operator is informed of any deviations in the process and is thus able to react at an early stage. Although welded products achieve good initial strength, it can still happen that long-term strength fails when the material overheats and the optimum strength is not achieved. Thermography can be used as an effective prediction tool in this case.

For laser transmission welding, it has only been possible to detect the heat of the top layer of the finished jointed component. Although this already allows reliable predictions to be made about long-term strength, LPKF expects the integration of TherMoPro into ATA technology to open new possibilities for quality control. ATA not only offers the possibility of looking directly at the molten joining surface, but also of analyzing both joining partners independently of each other.

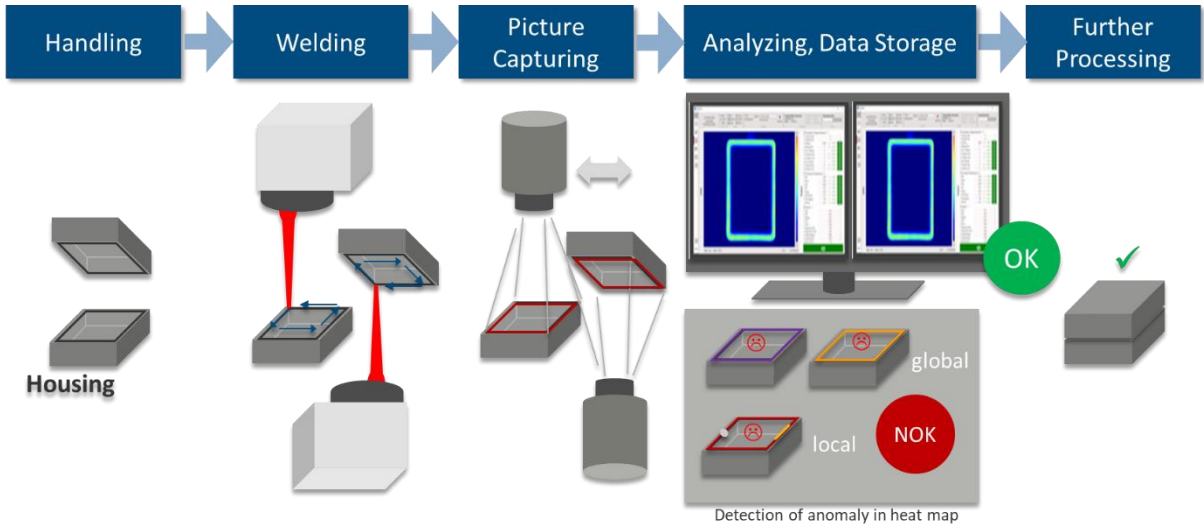


Figure 7: sequence of thermography analysis using TherMoPro

## 5. New applications for laser welding through ATA

**High requirements in the automotive sector** show a high demand of semi-crystalline plastics such as PPS. These are often equipped with specific fillers that serve to provide flame retardancy or electrical conductivity. Since both aspects impair transmission, many products today are joined using heating element or infrared welding. These technologies generate a large amount of heat, which can easily damage expensive internal electronics through overheating. ATA laser welding can remedy this situation, as only the weld bar to be melted is heated, thus ensuring a clean process.

**In the medical sector**, the aim is to achieve a **clean and safe process**. Sterilizable high-performance plastics such as PEEK in light colors are often preferred. Popular joining methods are gluing and thermal fusion bonding. Unfortunately, gluing offers few options for quality control, is difficult to recycle, and often contains toxic additives. The thermal fusion bonding, on the other hand, is very slow, costly, and inflexible. ATA requires no additives, offers a reliable quality control tool in TherMoPro, and impresses with its cost-effectiveness.

**Creative freedom for the consumer sector** shows in the great variation in terms of geometric and color designs. The challenge for laser transmission welding arises from the resulting complex geometries and optical properties of color-uniform joining partners. Ultrasonic welding or gluing are often used in such cases. Integrated mechanically sensitive electronics or specific environmental requirements also pose challenges for these processes. To achieve the required degree of freedom, these products can now also be joined using ATA.

## 6. Conclusion

Laser welding offers unique advantages when joining plastic components. Due to limitations imposed by the top layer, laser transmission welding has restricted access to many areas of application. These restrictions do not apply to the ATA process. This offers new options in terms of material selection, component design, additives, and color design. LPKF impresses with an outstanding mechanical concept, in-depth process understanding, and extensive analysis options. Its innovative potential is opening new fields of application in the automotive, medical, and consumer sectors.

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