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Investigations on the influence of the material selection of the clamping device during laser transmission welding of multi-layer polymer films with wavelength-adapted laser beam sources

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Abstract

In laser transmission welding process of polymers with wavelength adapted laser beam sources, the joining partners are fixed in an overlap arrangement. A sufficient energy absorption is ensured by addressing the material-dependent intrinsic absorption bands. The fixing is realized by a clamping device to achieve a technical zero gap between the joining partners in order to ensure heat exchange and melt permeation. The materials are in direct contact with the polymers and influence the heat dissipation as well as the propagation of the laser beam. While the upper material must be transparent for the laser radiation, a variety of materials are available for the lower part. Hence, it is investigated how the individual material combinations affect the process. To investigate the influence of material combinations as well as the influence of roll-to-roll processing or possible process limits welding tests are performed. The weld seam is analyzed by cross sections and weld seam width.

Keywords: Laser transmission welding; Polymer; Multi layer films; Roll 2 Roll; Adapted Wavelength

1. Introduction and current state of technology

In the laser transmission welding process, the two joining partners are positioned and fixed in an overlap arrangement. The fixation serves to achieve a technical zero gap between the components and thus to achieve heat conduction and melt mixing. In the absorber-free laser transmission welding process, both components

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are irradiated by the laser beam. The energy introduced can be described by the material-dependent absorption in depth and the energy density. Typical absorption capacities of the two joining partners in total lie in a range from a few percent to about 40%. This means that in absorber-free laser transmission welding, there is always laser radiation attenuated by absorption in the material after it has passed through the material stack. This laser radiation can then in itself interact with the materials of the surrounding system. These can be, for example, components of a clamping system for applying the necessary joining pressure. The materials of the clamping system are in direct contact with the polymer films. In most cases, polymers have a low thermal conductivity. Due to the low thickness of polymer films, mostly within the Rayleigh length of the laser optics, it is to be expected that the optical properties, but also the heat conduction properties of the pressure material, have a much stronger effect on the melt formation within the joining zone than is the case with thicker materials. There are various concepts for realizing the pressure on the top surface. These include glass plates, glass spheres, coaxial air jets, clamping goggles or even thin films that can be placed under vacuum. While the upper pressure body must necessarily consist of a material or medium that is transparent to the laser radiation, the material of the base can be freely selected in many applications. Thus, the choice of the substrate material represents a parameter that can be easily controlled.

2. Experimental setup

In order to specify the influence of different clamping materials on the welding process more precisely, different clamping materials are used on the underside with otherwise constant laser parameters. On the upper side, an industrially established glass plate is selected for better comparability. A LIMO diode laser system with a peak laser wavelength of 1660 nm, an optical power of 60 W at the workpiece surface, a fiber core diameter of 600 µm and focusing optics of 200 mm focal length is used for the experiments.

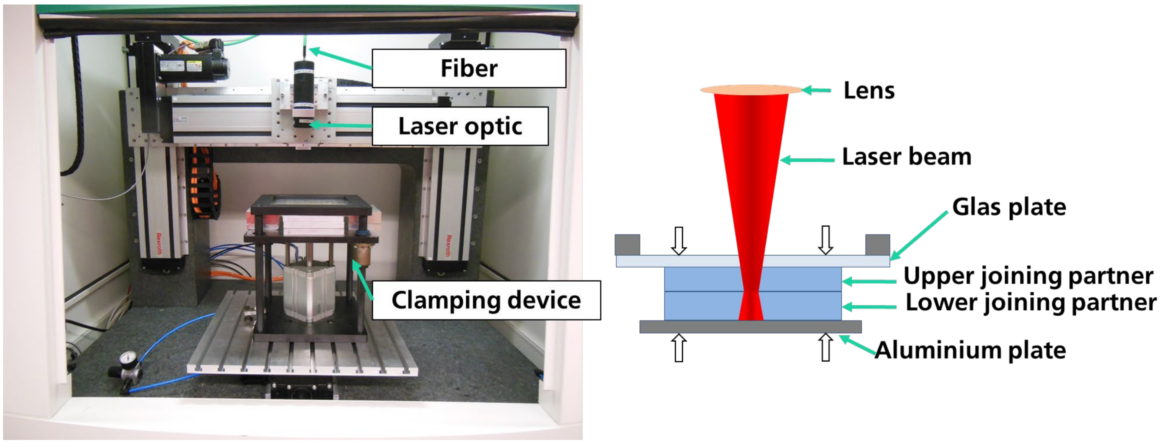
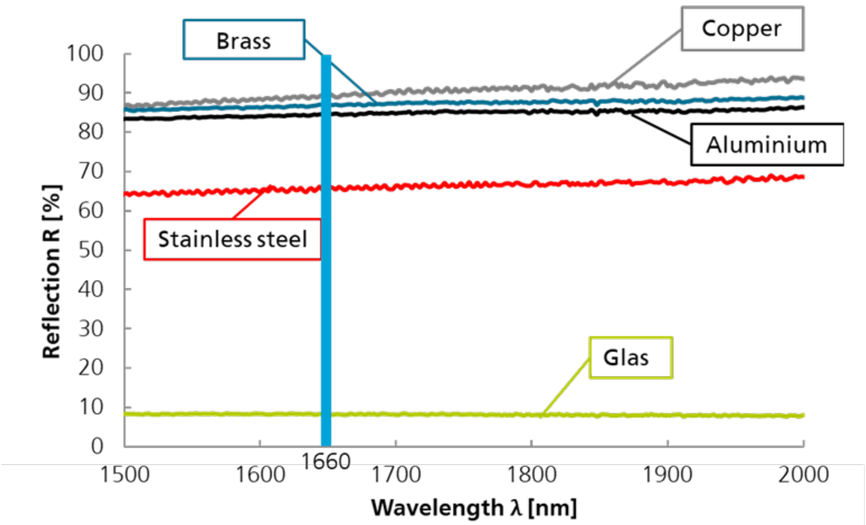


Fig. 2. Experimental setup

For the comparison, five different materials are selected on the underside that have become established in the field of laser transmission welding of polymers. These materials are chosen so that they differ greatly in both their reflective behavior and their thermal conductivity properties. Figure 2 shows for the selected materials, the measured optical properties as well as the heat capacity and thermal conductivity of the respective materials. To measure the reflection of a polymer a two beam Lambda 1050 UV/VIS/NIR spectrometer from Perkin Elmer Inc. of Waltham, Massachusetts, USA with an Ulbricht sphere setup is used.



Material	Specific heat capacity [J/gK)]	Thermal conductivity [W/mK]
Aluminium	0,89	235
Glas	0,84	1
Copper	0,38	394
Brass	0,377	120
Stainless Steel	0,477	15

Fig. 2. Optical properties of substrate at applied laser wavelength

Since glass, or more precisely quartz white glass, is also industrially established in many laser polymer welding applications and has the lowest thermal conductivity, the process parameters are suitably selected for this application. White glass thus represents the reference for the further investigations. For the selected commercially available polymer film consisting of 12 µm PET and 90 µm PE, the entire process window is now mapped in equidistant steps using a feed rate variation. A range of 4-12 mm/s is selected for this. All other parameters are now kept constant within the scope of the technical possibilities and only the material of the substrate is changed.

3. Results

The evaluation is based on a comparison of thin sections and measurement of the weld width. To measure the welding seam width a Keyence Corporation, Osaka, Japan (Modell VHX 900F) is used. The best welds in terms of both strength and visual impression are marked in cyan. As expected, the results show a strong influence of the substrate material on the welding process itself. For white glass, the optimum lies in the middle (8 mm/s) of the range considered and thus represents the complete process-relevant range from adhesion to decomposition.

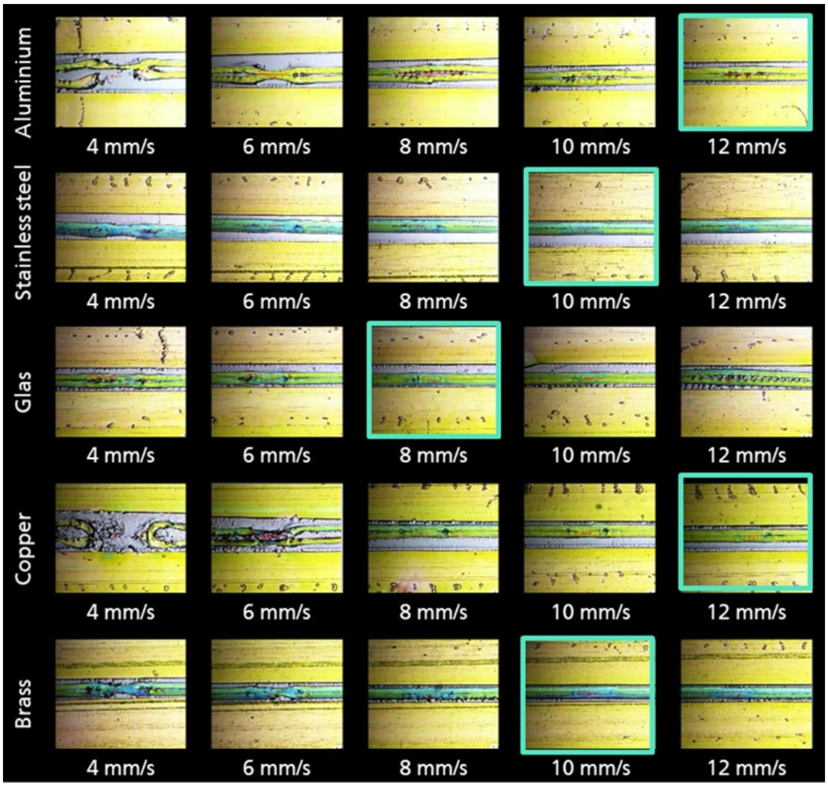


Fig. 3. Results on the influence of the material of the substrate

For the other materials, the welds defined as good all lie in higher process velocity ranges. This can be explained by the significantly higher reflection than for the white glass. Effects of reflection seem to dominate here. On the other hand, the strong destruction at lower feed rates is particularly noticeable for copper and aluminum. The laser radiation propagated through the material stack is reflected by an average of 85% and passes through the material stack again. This means that a higher amount of energy is deposited, resulting in higher process efficiency. Stainless steel has a higher reflection than glass, but at 65% is below copper, aluminum and brass. This is also reflected in the results.

If the previously considered thermal conductivity is put into relation, it can be seen, that the destruction threshold tends to become smaller with greater thermal conductivity. One explanation for this is that the pressure material heats up locally below the actual interaction zone through interaction with the laser radiation. This leads to an accumulation of heat, or in the opposite case to a dissipation of heat (copper), so that the highest temperature is not reached in the area of the joining plane, but possibly over the entire material cross-section. However, this influence seems to be superimposed by the influence of the optical properties. To consider the influence of the thermal conduction properties in isolation, further investigations are necessary. A possible approach would be the use of a numerical thermal simulation model or the use of surface-treated materials to normalize the reflection.

4. Conclusion and outlook

The influence of the material selection for the clamping device can be demonstrated. The results should be taken into account if the material of the fixture is to be freely selected in order to achieve the most efficient welding process at higher process speeds. Reflective properties and heat conduction properties can be identified as effects. By using highly reflective material, the laser radiation still present after the first pass can be guided through the foil stack again. This makes it possible to increase the efficiency of the process. In roll-to-roll applications in particular, this is of interest because especially high feed rates are required here. Influence trends of the heat conduction properties of different materials can be observed, but their influence on the welding process cannot be clarified exactly, since the optical properties also change when the material is changed and thus an isolated observation is not possible. Therefore, future work will focus on the influence of the optical properties and the heat conduction properties in isolation from each other.

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