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Strong connection: welding of different kinds of glass using femtosecond laser pulses

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Abstract

In this paper, we report on latest welding results of different glass substrates. All substrates have been welded by utilizing a femtosecond (fs) laser of the TruMicro series 2000 applying a pulse duration of 300 fs. The research focuses on welding of fused silica and alkali- aluminosilicate glass. We report also on results of alkaline earth boro- aluminosilicate and borosilicate glass bonds.

The femtosecond laser source has been applied on welding two optically contacted samples. To generate a dedicated melt volume different parameters have been varied during the study. Aside from the number of pulses within a burst train the base frequency has been determined as one important parameter to control the generation of a suitable melt volume.

After joining the glass samples the quality of the welded seams have been evaluated. Besides the quality, the stability of the welds was examined.

Keywords: micro processing, femtosecond, ultra-short laser pulses, glass, welding

1. Introduction

In recent years, glass became more and more important for different applications due to its exceptional optical, mechanical and chemical properties. This in turn led to the development of further new applications, which require to separate or bond different kinds of glass (Schaeffer und Langfeld 2014). State of the art

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glass bonding technologies include for example, adhesive bonding, soldering, optical bonding or diffusion bonding (Schaeffer und Langfeld 2014).

Beside the above mentioned bonding technologies welding of glass substrates using Ultra-short pulsed (USP) lasers have been conducted in many research projects since the early 2000s (Schaffer 05/2001) (Tamaki, Watanabe und Itoh 2006) (Mao, et al. 2004) (S. Richter 2013) (Zimmermann 2011). By means of extremely short pulses, nonlinear absorption processes start the internal modification in transparent materials (Stuart, et al. 1996). With help of this local energy deposition, structures can be machined in the submicron range (Hirn 2015). Ultra-short pulses at high repetition rates or even burst pulses enable a defined increase of the temperature close to the focal position (Tamaki, Watanabe und Itoh 2006) (Mao, et al. 2004).

By means of heat accumulation, transparent materials can be interconnected locally in this way (Tamaki, Watanabe und Nishii, et al. 2005) (Tamaki, Watanabe und Itoh 2006) (Zimmermann, et al. 2013) (Richter, Döring, et al. 2011) due to the generation of a dedicated melt volume.

Up to now welding of fused silica, borosilicate and soda lime glass has been deeply investigated and demonstrated in many research studies (Miyamoto, et al. 2010) (S. Richter 2013) (Zimmermann, et al. 2013) (Hand, et al. 2016). In a few industrial applications this technique already is implemented successfully and already replaced conventional bonding processes (Kaiser 2016).

Beside fused silica (hereinafter called FS) and borosilicate (in the following BS) in some industrial applications, other types of glass are in use. These are for example alkali- aluminosilicate glass (Corning® Gorilla® hereinafter called CG) or alkaline earth boro- aluminosilicate (Corning® Eagle XG® in the following CE). While FS is the standard material for optical technologies, BS usually is applied for medical engineering applications. The other two material types however frequently are utilized in fields of consumer electronics.

In this work we demonstrate the welding behavior of four different types of glass (mentioned above) utilizing a TRUMPF TruMicro 2030 femto edition. We first demonstrate recent welding parameters for FS and BS and evaluate the weldability for CE and CG, respectively.

2. Experimental set-up

The trials have been performed on a high precision micro processing machine with an accuracy in the range of one micron in x, y and z direction. For material processing a TRUMPF TruMicro 2030 femto edition was used. The used laser, emitting light at a wavelength of 1030 nm, delivers an average power of 20 W at a measured pulse duration of 350 fs. These kinds of lasers are based on (Chirped Pulse Amplification) CPA technology with a linear fiber amplifier. The monolithic design provides a very stable and reliable system. The frequency is adjustable in the range of 125 to 2000 kHz. Below 500 kHz it offers the possibility to define different bust patterns (cf. Table 1). As a focusing optics a microscope lens (Thorlabs LMH 10x) with an effective focal length of 20 mm has been used. To detect the sample surface and the interface between two samples in a suitable way a confocal laser sensor (KEYENCE LT-9030M) has been applied.

Table 1. Laser parameters, corresponding values and picture of the laser head

Laser parameters	Values	Picture
Wave length [nm]	1030	
Repetition rate [kHz]	125-2000	
Average power [W]/Max. pulse energy [µJ]	20 / 20	
Bursts / Burst frequency [MHz]	up to 8 / 50	
Pulse duration [fs]	350	

Fehler! Verweisquelle konnte nicht gefunden werden. shows a sketch of the used set-up. The laser beam is deflected by mirrors and focused perpendicular onto the work piece by means of a microscope lens. The sensor, used for pre-process measurements, has a lateral offset towards the focusing lens.

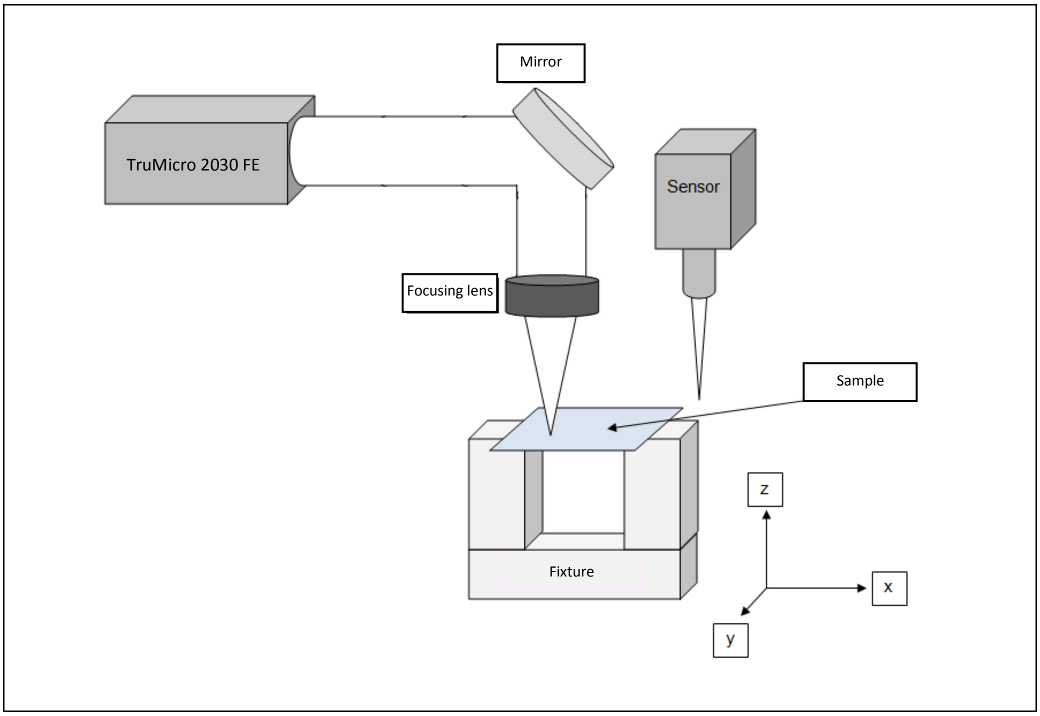


Fig. 1. Set-up for glass welding trials

The glass samples were optically bonded before welding. To achieve a higher adhesion coefficient between two substrates a droplet of methanol has been applied in between. The welding seams have been evaluated optically by means of different optical microscopes. In some cases, the welded samples have been forced by a mechanical load to check the welding connection.

3. Results

3.1. Laser-induced material modification

Fig. 2 shows selected results of typical thermally induced modification shapes comparing the four different types of glass (from left to the right: FS, CG, CE, BS). The upper row shows a side view at the interface of two bonded glass substrates. Additionally in the lower row welded seams are depicted in a top-down view.

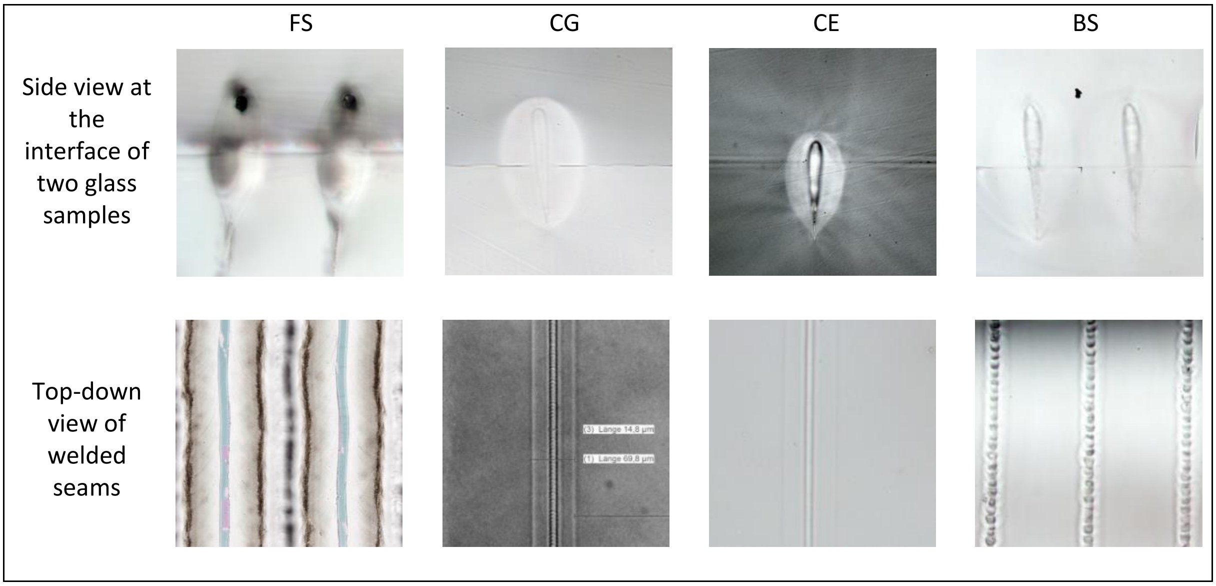


Fig. 2. Overview of different forms of welding connections. Upper row: side view at the interface of two glass samples. Lower row: Top-down view of welded seams for the different used glasses

In all cases the welds are placed at the interface of the two samples. The seams were done by using continuous speed, which was adapted on the lateral modification size. Depending on the type of glass, however, the welding seams look completely different and reach various dimensions.

For FS the modified volume was large compared to the other materials. The modification height was measured to 520 µm accompanied by a width of 150 µm. Whereas for CE and CG the modified volume reached a height of 110 µm (CE) and 140-160 µm (CG) accompanied by a width of 60 µm (CE) and 80 µm (CG). On BS, the modification approximately reached 240 µm in height in combination with a width of 80 µm.

The various results were determined by the different properties of the used types of glass. For FS a significantly higher average power (~ 9 W) was used to achieve a uniform weld while for CE and CG the maximum power was set to approximately 1.4 W. The average power was set to 2.5 W for BS.

Fig. 3 shows the side view and the top-down view of a weld seam on CG at optimum performance parameters. The images on the right show a result when the power setting was too high. In this experiment 3 W average power was used.

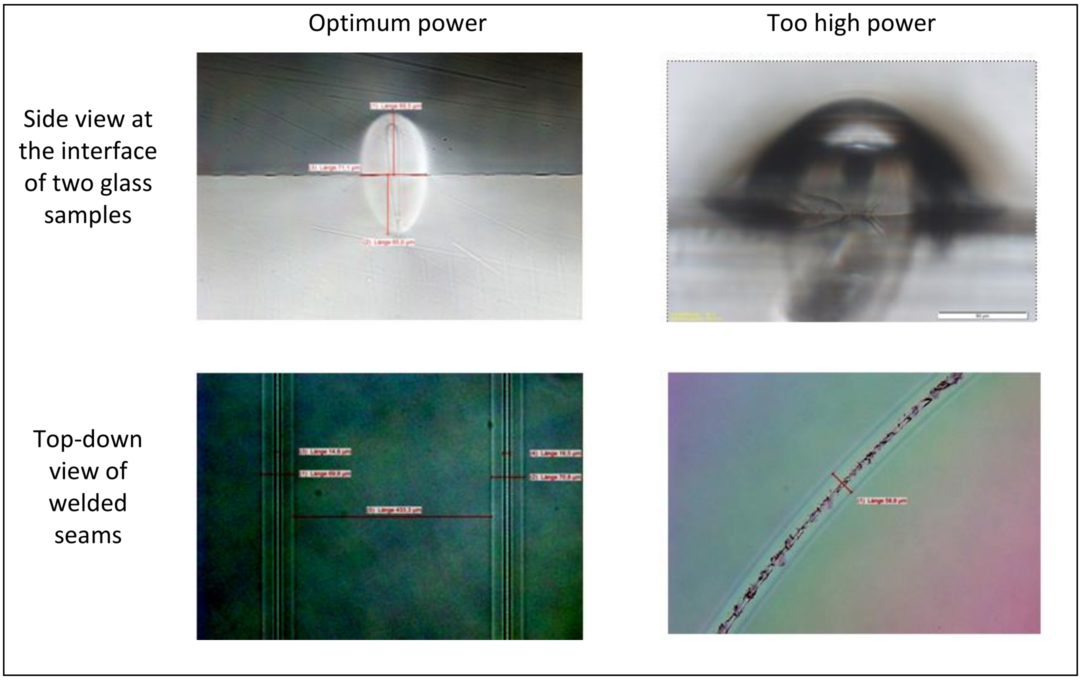


Fig. 3. Comparison of two welding results (upper row: side view, lower row: top-down view), left column: optimum power range, left column: average power was too high

This in turn led to cracks within the welding seam. However, the maximum usable power in a welding process directly affects the dimensions in height and width. This, in turn, has an effect on the sensitivity of the welding process. The lower the modification size, the more external facotors can interfere with the welding process. A displacement of the focus position on CG by +/- 10 µm already can lead to an unstable process.

In Fig. 4 the focus position was set too low (left column) or too high (right column). Only the position depicted in the middle (focus position optimal) was suitable to bond two glass samples.

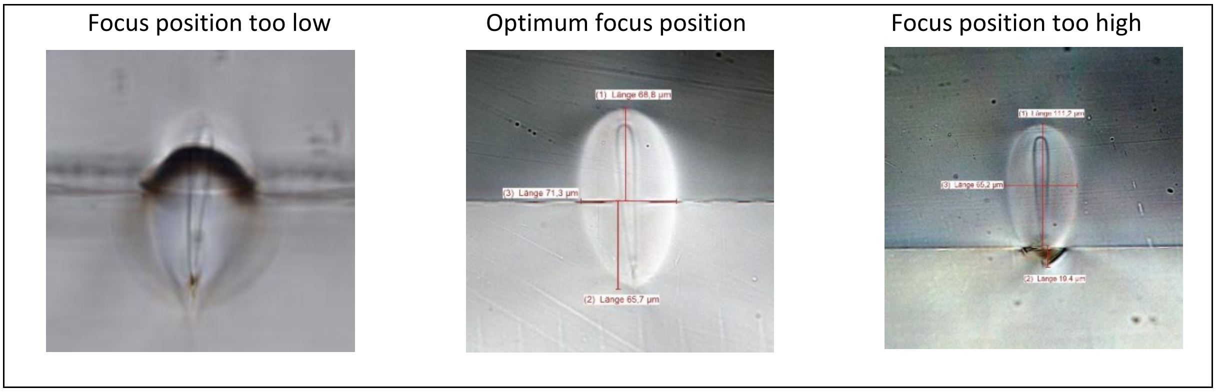
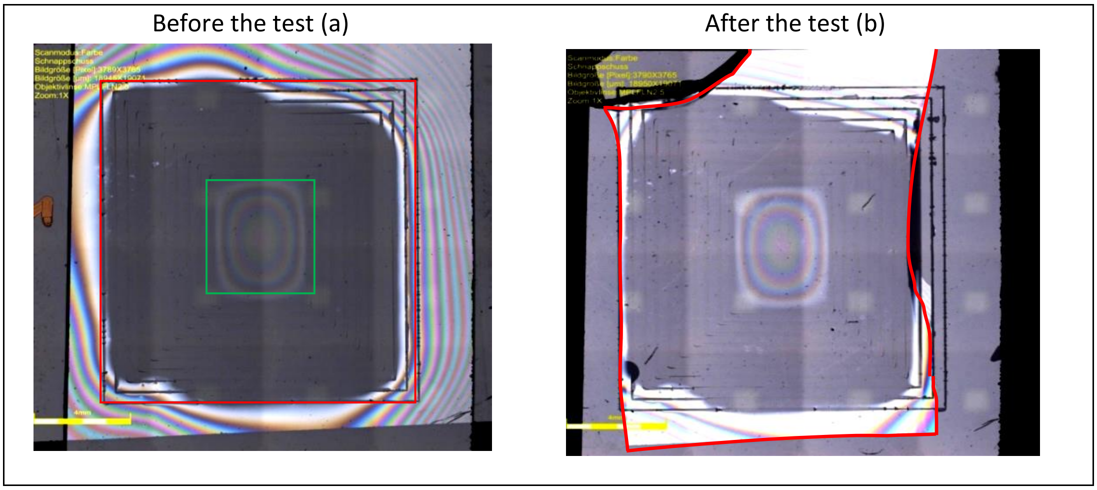


Fig. 4. Comparison of different focus position on CG glass (cross section)

3.2. Strength of the welded connection

As shown above for all kinds of glass good looking parameters were found to connect two identical material samples. In order to test the strength of the welded seams, the load capacity of two welded CG glass samples was investigated.



Before the test (a)

After the test (b)

Fig. 5. Test of the welded connection. (a) Two sealed glass samples before the strength test, (b) two sealed glass samples after the test

For this purpose, two rectangular glass samples were twisted by 90° to form a square contact surface of 25 mm by 25 mm. Within this contact surface 10 differently sized square shaped seams were welded in order to establish a firm connection between the two glasses. The green and the red square (Fig. 5, a) represent the innermost and the ultimate weld seam, respectively. The line spacing between the seams was set to 0.5 mm. The same picture also shows that not all areas are correctly joined together. The Newtonian rings make it very easy to see which areas are welded and which are not. The dark areas in the picture are well connected. On the other hand, the ring structure is visible if the area is not connected well. Nevertheless, this partly welded sample was subsequently loaded with pressure to the lower glass plate. The pressure applied to the glass sample was determined by means of a scale. The sample broke at a load of 14.7 N. As a result, Fig. 5 b shows that most of the welded seams had withstood the load. In the outer areas the fracture is visible. In this area, the sample was not optimally welded previously. In the same picture red lines mark the fracture points. With this test it could be shown that obviously good welded areas are strong enough to withstand a certain mechanical load.

4. Conclusion

In this work, we investigated the weldability of four different types of glass with the TRUMPF TruMicro 2030 femto edition. We could show that all tested materials (fused silica (FS), Corning® Gorilla® (CG), Corning® Eagle XG® (CE) and Borosilicate (BS)) are weldable. It came up that in some cases there are major differences in the modification size, concerning the width and the height as well. This is caused by the different thermal properties of the used materials. On FS a significantly higher power could be implemented than on the other used glasses.

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