Lasers in Manufacturing Conference 2015

Laser joining of glass and metal

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Abstract

Joining of glass and metal is in the most cases realized by ultrasonic welding, soldering or gluing. Another possibility is the direct bonding of glass and metal by glazing. This technology exists since more than 100 years. Most prominent examples are the light bulb or the television tube. At the moment, this technique is developed for additional applications in combination with the new tool laser. Actual examples are solar collector tubes or X-ray tubes. Here the most important requirement is the vacuum tightness for several 10 years. In the industry this process is realized with burners in semiautomatic processes.

This paper shows a new processing method for the combination of glass and metal with CO_2-laser radiation. Fundamental material properties of the bonding partners, physical and chemical correlations and the following process steps will be discussed. The presentation of the system techniques and the process cycle gives an overview of the level of automation and the aspects for production, like process time and laser power. The research in joining glass and metal regarding to stability, mechanism of bonding and the internal stress will allow for the evaluation of this joining method. An outlook for further steps in the development of this procedure will complete this article.

Keywords: joining; surface functionalization; process control; system technology

1. Introduction

Glass-metal-combinations are used in a plurality of products. Some examples are lamps, implementations of electricity, X-ray tubes, laser tubes, chemical constructions, as well as applications in medical technology and life science. A new but also ambitious application is the manufacturing of solar collector tubes for the use in parabolic trough power plants. Here the very high demands cannot be realized by classical joining technologies. However, with the process of glazing all demands regarding to thermal and mechanical loads, vacuum tightness, chemical resistance and longtime stability can be complied [1].
The developments have two goals. The first one is replacing the conventional flame burners with CO_2 laser radiation to avoid actual problems like varied heating, contamination and difficult automation. The second

one is the development of thermally unadapted bonds to replace the very expensive materials like Kovar and Schott 8250 with low cost standard materials.

2. Experimental setup

The test setup for the fabrication of axially symmetric glass-metal-bonds consists of two opposite rotary axes, which are mounted oppositely on two linear axis. The CNC-controller allows all variances in moving of glass tube and metal ring. Integrated in the system is a temperature controlled laser power regulator, which is connected with a ROFIN DC035 CO_2-laser.

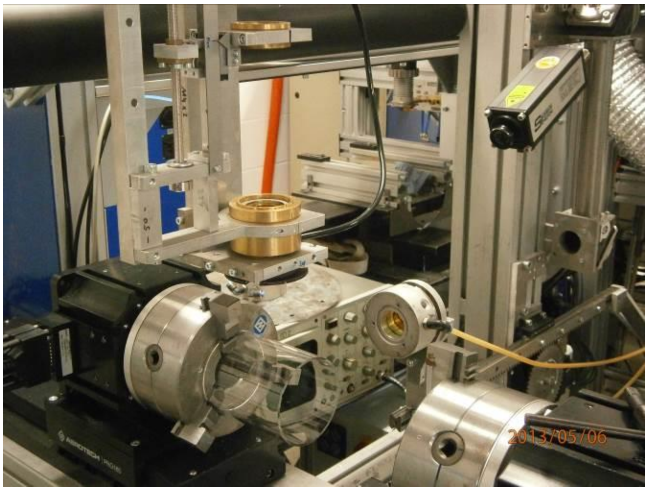


Figure 1: Experimental setup with axis system, optics and pyrometer

To adjust the temperatures and viscosities of the glass for the joining process in the range of the joining zone, the beam shaping is a very important factor. The optimization of the laser beam geometry has positive effects on the quality of the joining and process time [2]. For different tube diameters, the beam geometry has to be adjusted. For a 75 mm tube, an example is given in Figure 2.

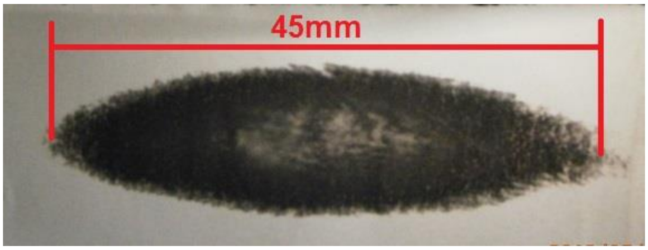


Figure 2: Laser beam geometry (tube Ø75x3.2)

3. Adapted bonds

The research in joining of adapted bonds with glass and metal was conducted with the glass material Schott 8250 and the metal part in Kovar 1.3981. Both materials have the same coefficient of thermal expansion in a range of $5.5 \cdot 10^{-6}$1/K. The pretreatment of the metal part is a very important task. To realize a save joining between glass and metal a special cleaning process is necessary, before the metal undergoes a defined oxidation. The difference of a cleaned and a not cleaned surface shows the following picture with 200x optical magnification. Grain structures are visible.

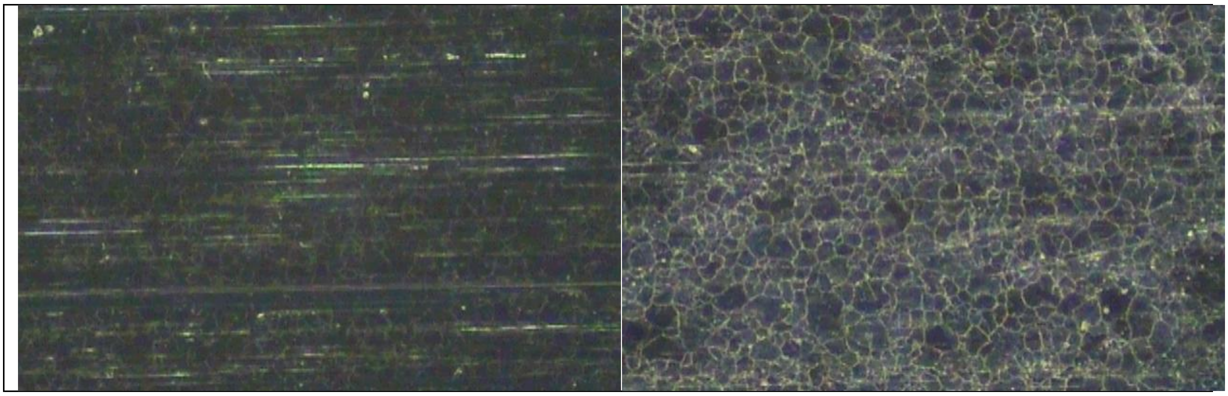


Figure 3: Left not cleaned and right cleaned Kovar surface

The most critical process step, before the joining of glass and metal, is the defined oxidation of the metal part. The studies in oxidation of flat material has shown, that the oxide FeO with his melt temperature of 1369°C is alone in the region of the processing temperature of borosilicate glass (1250°C). Furthermore, it works as a network modifier because of its molecular structure which is similar to the glass network. So, the desolving of the oxide in glass is possible [3]. In Figure 4 the upper row shows the glazing with a mix of the oxides FeO, Fe_2O_3 and Fe_3O_4, while the lower row shows the successful glazing purely with the oxide FeO.

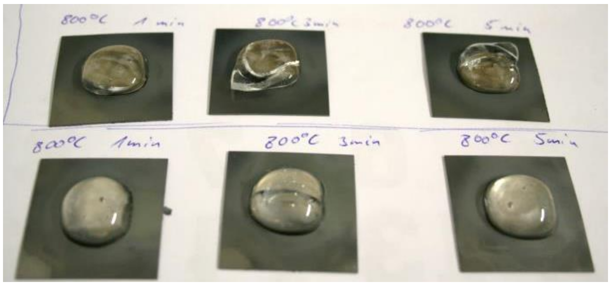


Figure 4: Glazing with a mix of oxides (upper row) and with FeO only (lower row)

Figure 5 shows the influence of the cleaning process. Without cleaning, the generated oxide is contaminated and has a lower adhesion to the ground material. With visual inspection, it is recognized that a higher generation of bubbles in the glass during the glazing prozess occurs, when the surface is not cleaned before the oxidation of the metal.

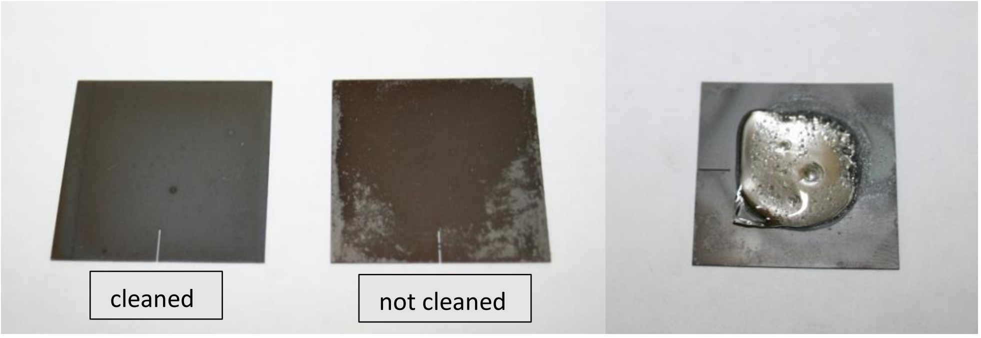


Figure 5: Influence of cleaning to oxidation and glazing

For the process in joining glass tube and metal ring the joining temperature is one of the most important parameter. The viscosity of the glass must be in a range, where it allows for plastic forming and gives the metal no important resistance in ingression. A viscosity of approximately 10^4 dPas complies with these requirements. During the developments, a glass temperature of 1200°C turned out to be the optimum for the glazing process. At this temperature the metal ring has the deepest ingress in the wall of the glass tube. If the viscosity is too low, the wall of the glass tube changes in shape and diameter because of the affected centrifugal force during rotation. When viscosity is too high, the metal ring does not ingress in the wall of the glass tube. The glass is displaced. Another important process parameter is the ingression speed. The speed must be relatively high in a range of 10mm/s to make use of the inertance of the glass.

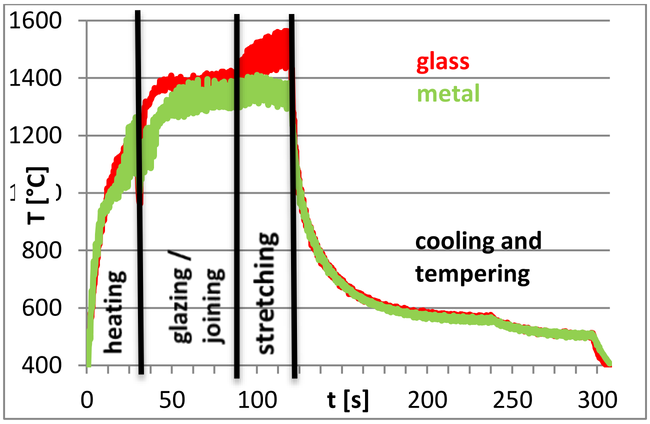


Figure 6: Temperature graph of the joining process

The diagram shows the time cycle of the joining process for a tube of 125mm in diameter. At the beginning, there is a heating phase. When both, the glass and metal reach the desired temperature, both partners are joined. In the following, the glazing process occurs. Here, the glass is heated to 1400°C. Caused by the decrease of the viscosity to approximately 10^3dPas the glass surrounds the metal better than at higher viscosities. Additionally, a positive effect of the high temperature is the better dissolving of the oxide in the glass. This procedure is the essential quality feature for a glass metal bond.

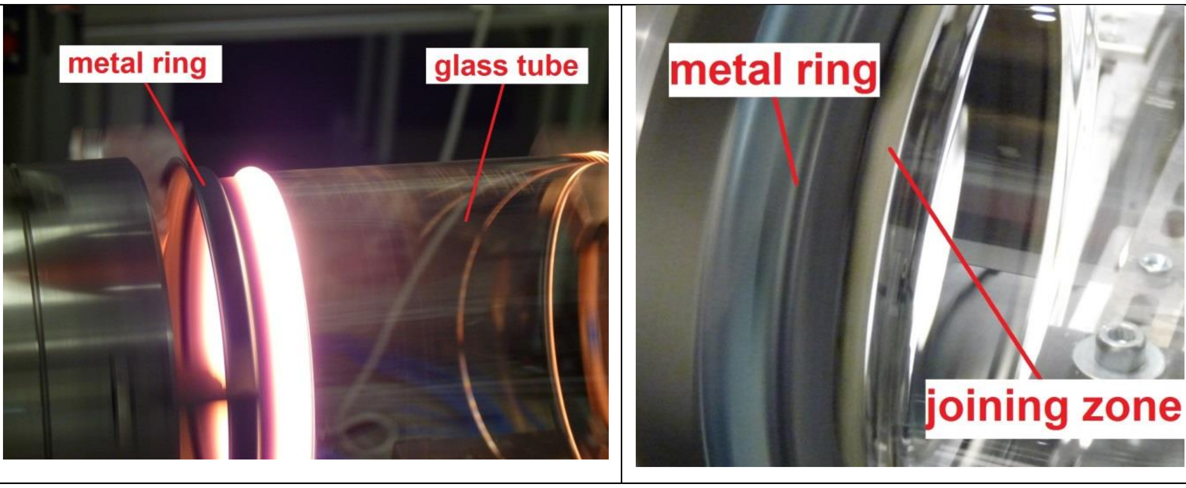


Figure 7: Glazing process and joining zone

4. Unadapted bonds

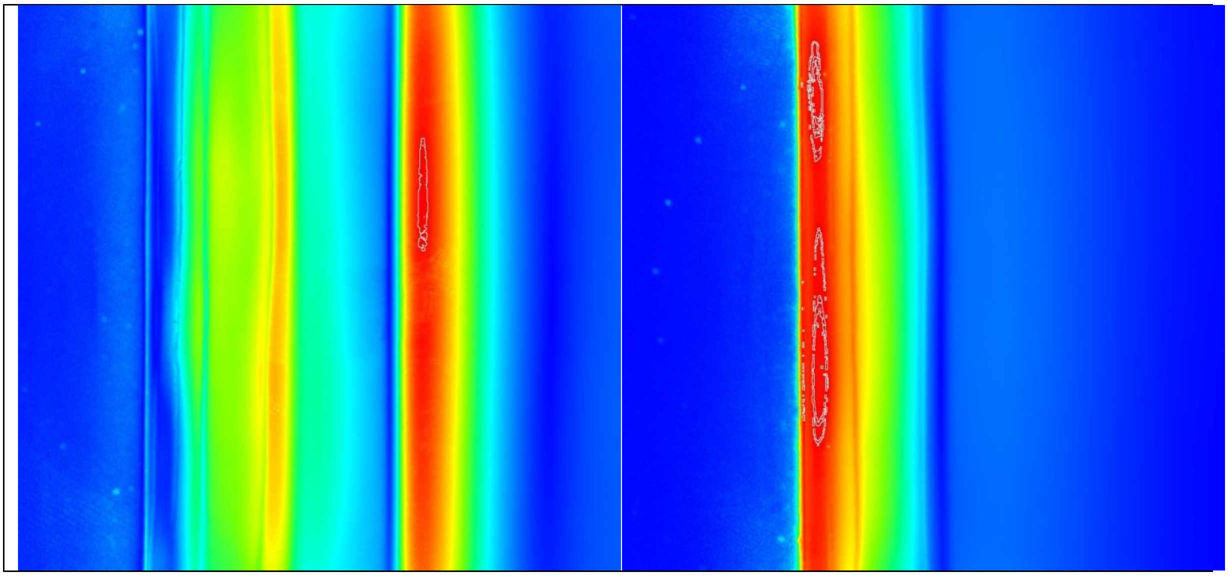
Caused by the high raw material costs with adapted thermal expansion coefficients, ideas and simulations exist to use cheaper standard materials for glass metal joining. Under special conditions, it is possible to join stainless steel with Schott 8330. Here the difference in thermal expansion is from $16 \cdot 10^{-6}$1/K to $3.3 \cdot 10^{-6}$1/K. By these bonds, called Housekeeper bonds, the metal part is very thin and angularly formed. So, a ductile and elastic deformation of the metal is possible. The most important fact is the very thin wall thickness of the metal ring in the wall of the glass tube. So, the thermal expansion causes only a low level of thermal stress in the glass material. Regarding to the cleaning process and the oxidation the same conditions as for adapted bonds apply.

To date, unadapted joining of Kovar and Duran (thermal expansion $5.5 \cdot 10^{-6}$1/K and $3.3 \cdot 10^{-6}$1/K) was performed successfully. Even this small difference in thermal expansion makes an adaption of the metal part necessary. The joining process works without adaption, but the crack in the glass tube in close proximity of the bond zone cannot be avoided. The reason is the higher thermal expansion of the metal in comparison with the glass.

Figure 8: Unadapted bond with a mix of oxides (left) and with FeO (right)

5. Evaluation

Directly after the process, the joint samples have a storage property up to some days without damaging resulted by cracks. Hence, a tempering process is still necessary. The expectation, that there is stress in the material, was confirmed by a measurement of the stress in the glass tube. It becomes clear that the stress in the glass material disappears, but on the border of glass and metal new stress is developed.



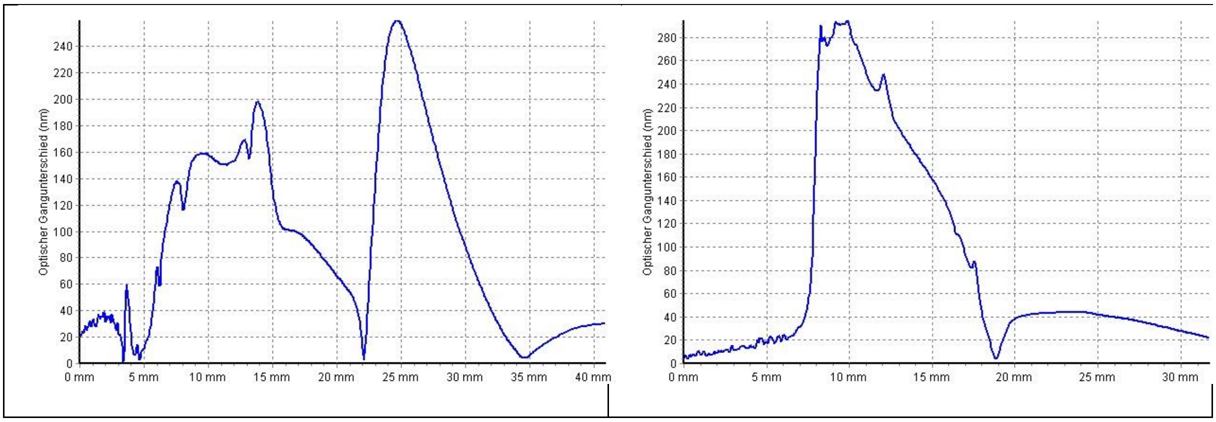


Figure 9: Measurement of stress before (left) and after tempering (right), miscolored map and line scan

The visual check shows, that an adhesive bond only exists, if the oxide is dissolved in the glass. The joining zone should look metallically bright. An EDX analysis gives information about the mechanism of the bond. Between the dark shown glass and the bright shown metal a light gray intersection zone is recognized. In this zone there is a mixture of glass (Si) and metal (Fe). The reason for this diffusion is the oxidation layer with the bivalent oxide.

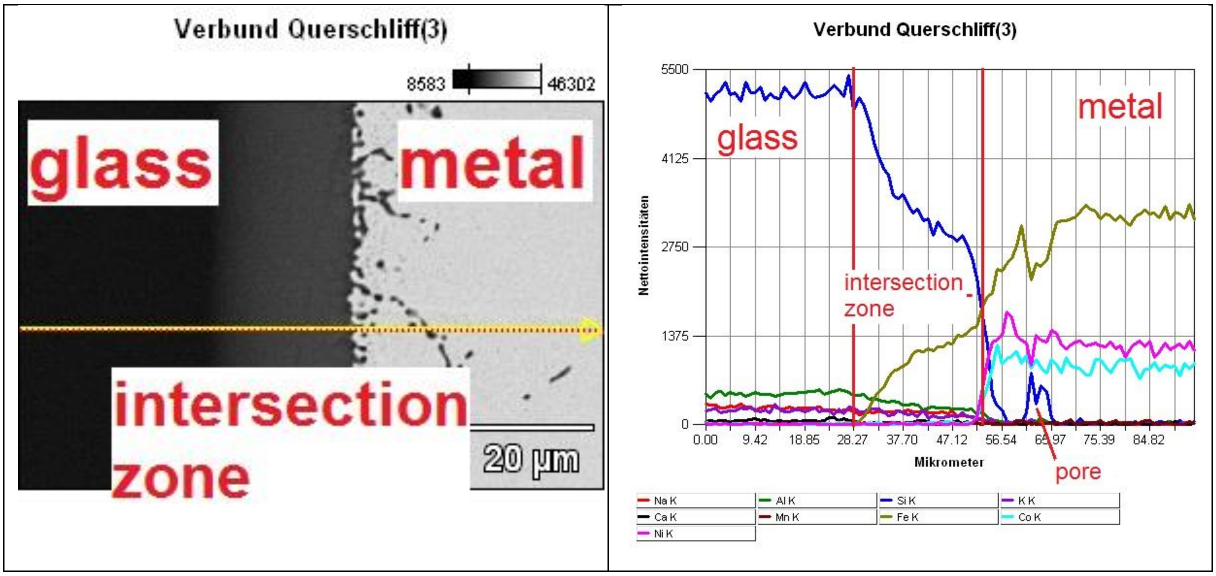


Figure 10: REM-picture and EDX-analysis of the joining zone

The graph in Figure 10 **Fehler! Verweisquelle konnte nicht gefunden werden.**on the right side documents, that from the glass to the metal the Fe-concentration increases and the Si-concentration decreases. In contrast, the other metal components like Ni or Co have no such a diffusion zone.

6. Numerical simulation

The simulation of the mechanical process (dipping of the metal ring in the wall of the glass tube) is very difficult. The large deformation of the elements in the numerical analysis requires an iterative new crosslinking. Hence, the focus was on the thermal processes. In consideration of the symmetry of tube and ring only a quarter of the part was simulated (Figure 11). Additionally, the model was reduced to the heat affected zone [4].
Basis for the generation of a thermal strain profile was the time and the appropriate laser power from the practical experiments. In comparison of the measured temperature with the appropriate thermal results of the numerical simulation a good agreement was reached. Based on the calculated field of temperatures a mechanical analysis was conducted. So, statements can be given about the stress in the range of the joining zone. In the picture below the internal stress in the glass and in the metal is shown.

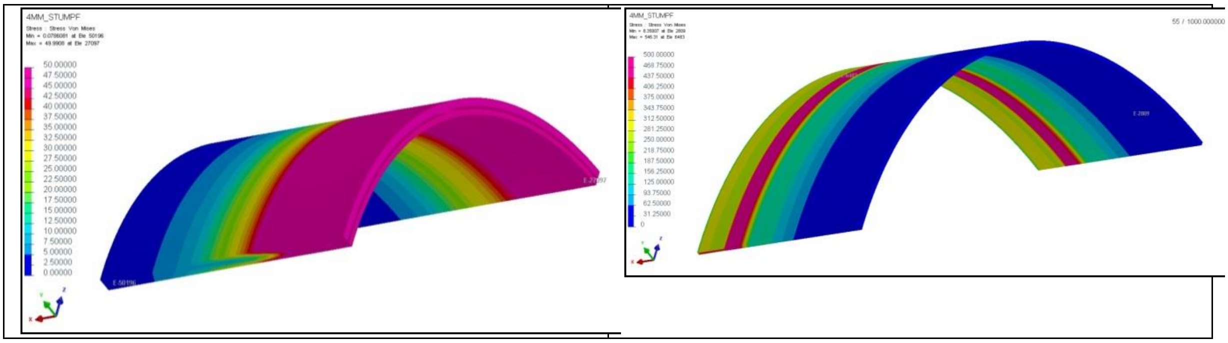


Figure 11: Internal stress [N/mm²] in glass (links) and metal

7. Summary

The modified test setup allows studies in the process development of axially symmetric glass metal joints. It could be documented, that adapted glass metal joining is realized with the use of CO_2-laser radiation. A field of parameters was developed, where all relevant parameters are included. The further work is focused on different geometries of tubes, material engineering and the transfer of the results to the unadapted bonds.

8. Acknowledgment

The project was supported by the Federal Ministry of Economy and Energy under grant number VF130003, following a decision of the German Bundestag.

9. References

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