Simulation of Temperature Field Distribution for Cutting the Tempered Glass by Ultraviolet Laser

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Abstract. The finite element software ANSYS was adopted to simulate the temperature field distribution for laser cutting tempered glass, and the influence of different process parameters, including laser power, glass thickness and cutting speed, on temperature field distribution was studied in detail. The results show that the laser power has a greater influence on temperature field distribution than other parameters, and when the laser power gets to 60W, the highest temperature reaches 749°C, which is higher than the glass softening temperature. It reflects the material near the laser spot is melted and the molten slag is removed by the high-energy water beam quickly. Finally, through the water guided laser cutting tempered glass experiment the FEM theoretical analysis was verified.

1. Introduction
Tempered glass is a kind of special glass formed by quenching after heating of flat glass. Due to its high bending resistance, high bearing capacity, no acute rupture and anti-thermal break ability[1,2], it is widely used in aerospace vehicles, weapons & equipment, automotive windshield, electronic products screen, high-rise buildings, doors, windows, furniture and so on[3,4]. However, during the process of being cut by laser, it is very likely to form the great uneven thermal stress in the cutting area on the tempered glass owing to its high hardness and brittleness, which will cause the crack or the fracture ultimately[5,6]. Salman Nisar [7] studied the influence of laser cutting speed on the stress by the finite element software ABAQUS, and the cutting path was also optimized. Tsai Chwan-Huei [8] used the thermal stress to induce the material to separate along the cutting direction while cutting LCD glass by the CO2 laser, and the formation mechanism of crack was analysed. Wang Xuhuang [9] from Zhejiang University of Technology used CO2 laser to initialize the initial crack in the liquid crystal glass substrate, and then heated by CO2 laser as a heating resource and cooled by Ar gas.
In the paper, the finite element software ANSYS was adopted to simulate the 3D temperature field on the tempered glass for laser cutting, and then the influence of the different process parameters, including laser power, glass thickness and cutting speed, on the cutting quality were analysed, which provided a solid theoretical basis for the experiment.

2. Simulation of the temperature field

2.1. Basic assumption

Before the numerical simulation of temperature field, the following assumptions were made\cite{10,11}:

(1) The laser energy is evenly distributed throughout the laser beam, and the energy of the laser beam is only absorbed by the surface layer. Thus, the laser is the surface heat source.

(2) The temperature field is a continuous unsteady heat conduction temperature field.

(3) Considering the reflective properties and brittle hardness of the tempered glass, the average values of the corresponding temperature range are adopted for numerical analysis.

(4) The heat flux in the laser processing period is a constant.

2.2. Physical modeling and meshing

According to characteristics of the laser forming process, a simplified 3D geometric model was generated. The size of the model is 10 mm x 10 mm, and the physical dimension also assure that the model boundary condition has no influence on temperature calculation. The thickness is equal to that of the tempered glass in the experiment. In the processing area, the grid remeshing technique was adopted to reduce the mesh distortion caused by thermal deformation so as to improve the accuracy of simulation calculation. However, the other majority part of the model was grided normally in order to improve the computation efficiency. The focused laser beam was considered to be an ideal Gauss Distribution and moved along the X axis at a speed of \( V \). \( I(x,t) \) was applied to simulate the absorption of laser energy on the surface of the workpiece, and it is converted into heat energy.

In the paper, the grid meshing was adjusted according to the idea above, as shown in figure 1. The minimum length of the element is setted to 0.2 mm for the processing region, and the maximum length of the element is setted to 1 mm. Finally, the amount of the elements was reduce to 19440 successfully by manual method.

![Figure 1. Grid remeshing](image)
2.3. Simulation results

2.3.1. Influence of laser power on temperature field distribution. In this situation, the glass thickness was selected as 0.5mm, the cutting speed V was setted to 1mm/s, and the laser power was selected as 40W, 50W and 60W successively for the following simulations.

Figure 2(a), (b) and (c) show the temperature field distribution at the same time(2 second) by different laser power 40W, 50W and 60W. It can be seen from the figure 2 that with the increase of the laser power, the temperature of the core cutting area on the surface of the tempered glass is gradually increased. When the laser power is 40W, the maximum temperature of the tempered glass is 528℃, which is lower than the softening temperature of the tempered glass. However, while the laser power reaches 50W, the temperature of laser spot center on tempered glass surface is reaching 623℃, which gets into the softening temperature range of the tempered glass. So it indicates that the material in laser spot center has already partially been melted. Nevertheless, away from the laser spot center, the temperature drops sharply until it gets to the room temperature. More importantly, when the laser power gets to 60W, the highest temperature on the tempered glass surface reaches 749℃, which is well above the softening temperature of the tempered glass. It indicates that the molten pool has already formed in laser spot center, and the material in the molten pool is quickly removed by the high energy water beam. So, 60W laser power is fitable for cutting the tempered glass.

Therefore, by controlling the laser power, the heating temperature on the surface of the tempered glass can be effectively controlled, and the direction of the crack on the tempered glass can also be controlled by changing the temperature field distribution.

![Figure 2](image)

**Figure 2.** Influence of different laser power on the temperature field distribution (a)40W, (b)50W, (c)60W

2.3.2. Influence of glass thickness on temperature field distribution. For this section, the laser power was setted to 60W, the cutting speed V was setted to 1mm/s, and the glass thickness were selected as 0.5mm, 1.0mm and 1.5mm for the following simulations.

As shown in figure 3, the temperature decreases along the glass thickness direction from the upper surface to the back surface with the continuous laser irradiation, and the maximum value is at the upper surface. In addition, the datas show the thickness has a significant influence on the temperature distribution along the thickness direction. The thicker the tempered glass is, the wider the kerf becomes, and it is harder to be cut off due to the molten pool is fixed with a certain laser power (shown in figure 3). So, 0.5mm thickness is a better choice.
2.3.3. Influence of cutting speed on temperature field distribution. In this part, the laser power was selected as 60W, the glass thickness was selected as 0.5mm, and the cutting speed $v$ were setted to 2mm/s, 4mm/s and 6mm/s respectively for the following simulations.

It is clear from figure 4 that the cutting speed is rather slow, so the time for laser working on the tempered glass gets longer. Thus it makes the effective spot area become larger which directly leads to a more wider kerf on the glass. Moreover, over melting reaction happens in the laser precessing area because the cutting speed is slower than that of material melting speed, and it will also cause a irregular and wider kerf.

However, in figure 4, cutting speed of 6mm/s is a little bit faster, thus the laser beam irradiates on the glass only in a relatively short time, so the laser spot runs over the material ahead but the material has not been well melt yet, which leads to a bad surface roughness, and some slag hanging on the kerf. So, $v=4\text{mm/s}$ is suitable.

4. Experimental Analysis

The laser cutting without transversal crack for the tempered glass experiment was conducted on HT-3P laser processing system (see figure 5) equipped with YPP300 fiber laser and the coupling device of micro water beam and laser beam.

Experimental results show the laser power has a greater influence on temperature field distribution than other parameters and the cutting surface of specimen with 0.5 mm thickness is smooth (see figure 6) while laser power is 60W, cutting speed is 4mm/s, as shown in figure 6. And there is no micro crack near the cutting area. The cutting kerf’s width is about 100 um, as represented in figure 7.
5. Conclusion

(1) The glass surface temperature gradually increases as the laser power increases. When the laser power gets to 60W, the highest temperature reaches 749°C, it reflects the material near the laser spot is melted and the molten slag is removed by the high-energy water beam.

(2) The cutting surface of specimen with 0.5mm thickness is smooth, and no transversal crack appears near the cutting area. The cutting kerf’s width is about 100 um.

6. References

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