Research Article

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Laser cutting tobacco slice experiment: Effects of cutting power and cutting speed

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Abstract: Due to their low melting point, low strength, uneven thickness, and sugar and moisture content, tobacco slices are very sensitive to the requirements of cutting parameters. In this article, the CO_2 laser is used to study the specific process parameters in the cutting process of tobacco slices with a moisture content of 13%. The cutting powers and cutting speeds are varied to investigate the effects on the cutting quality of tobacco slices. The result reveals that the lower the cutting speed, the more conducive to the cutting of tobacco slices. And cutting speeds less than 2.5 m/s are preferable to the cutting of tobacco slices. But lower cutting speed means lower cutting efficiency. Meanwhile, the larger the cutting power, the more conducive to the cutting of tobacco slices. However, larger cutting power means larger energy consumption and higher requirements for the laser. Therefore, there is a compromise between cutting speed and cutting power. The preferable cutting power and speed parameters are summarized. The results obtained provide practical guidance for cutting high-quality tobacco slices.

Keywords: laser cutting, tobacco slice, cutting power, cutting speed

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1 Introduction

Laser is a kind of light amplified by stimulated emission of radiation, which is another major invention of mankind since the twentieth century, following nuclear energy, computers, and semiconductors [1,2]. The laser is compared to the fastest knife, the most accurate ruler, and the brightest light. Thus, laser processing technology has been widely used in cutting [3–5], welding [6–8], surface treatment [9–11], marking [12–14], and precision machining [15–17], especially in cutting.

Laser cutting is a technology that uses a focused high-power-density laser beam to irradiate the workpiece to quickly melt, vaporize, ablate, or reach the ignition point of the irradiated material. At the same time, the molten material is blown away by the high-speed airflow coaxial with the beam to realize the cutting of the workpiece [18]. With the small laser spot, high energy density, and fast cutting speed, laser cutting can obtain better cutting quality. Thus, laser cutting is widely used for cutting different kinds of materials [19–21]. The three-dimensionally printed acrylonitrile butadiene styrene plates were cut by laser for dimensional and surface roughness optimization [21]. Laser precision cutting of polydimethylsiloxane (PDMS) films was investigated by Wu *et al.* [22]. The mechanism of ultraviolet (UV) nanosecond laser precision cutting of PDMS films with laser ablation as the core was explored based on an analysis of by-product components. In addition, Vasileska *et al.* [23] researched the in-line monitoring of focus shift by kerf width detection with coaxial thermal imaging during laser cutting. An algorithm was proposed to monitor the kerf width and yield the estimated focus position in real-time during the cutting process. And the product quality in pulsed laser cutting of silicon steel sheet was predicted using vibration signals and a deep neural network [24]. It can be seen that laser processing and its related technologies are widely used in various fields. Among them, tobacco slice is a kind of slice, and its cutting method is also changed from traditional hob cutting to laser cutting [25,26]. However, there are few studies on the specific process parameters in the laser cutting process of tobacco slices. Tobacco slices have low melting point, low strength, uneven thickness, and contain sugar and moisture, so they are more sensitive to the requirements of cutting parameters. Thus, it is necessary to study the cutting parameters of tobacco slices.

In this article, we use a CO_2 laser to study the cutting of tobacco slices. The cutting power and cutting speed are varied to investigate the influence on the cutting quality of tobacco. In addition, the cross-sectional morphology of tobacco slice is analyzed. Furthermore, the optimal conditions for laser cutting of tobacco slices are researched.

2 Experimental system

2.1 Laser cutting optical path system

A CO_2 laser (DIAMOND J-3-10.6, COHERENT) was used to cut the tobacco slice, and the cutting of tobacco slices was accomplished using galvanometer scanning. The schematic diagram of the double laser beam cutting optical path system is shown in Figure 1, and the optical parameters of laser system are listed in Table 1. According to Eq. (1) [27], the depth of focus of the focal length (DOF) can be calculated based on the optical parameters of the laser system. The double laser beam cutting optical path system had two lasers with the same model and characteristic parameters. The processing light source was converted by the optical path system and was incident on the X-axis galvanometer at a certain angle. After reflection, the included angle remained unchanged. The light was reflected by the Y-axis galvanometer and finally passed through the flat field focusing lens, forming two light spots on the surface of the processed material. When the X- and Y-axis galvanometers rotated, the two beams of light would move at the same time, which could shorten the cutting and scanning time and improve the cutting efficiency.

$$\begin{cases} 2\omega_0 = \dfrac{4M^2\lambda f}{\pi D} \\ \mathrm{DOF} = 2\dfrac{\pi\omega_0^2}{M^2\lambda} \end{cases} \tag{1}$$

where M^2, λ, f, D, ω_0, and DOF are the mode quality, wavelength, focal length, beam diameter at lens, beam diameter at focus, and DOF of the focusing system, respectively. Based on the optical parameters of the laser system in Table 1, the DOF can be calculated and is about 99 mm.

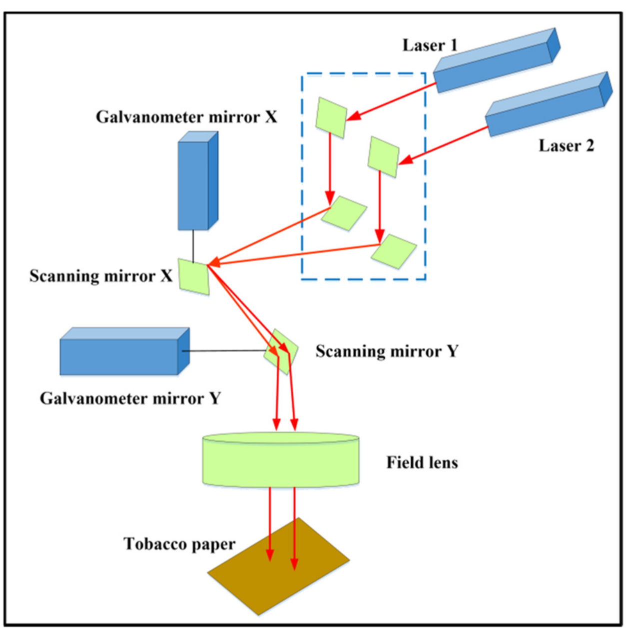

Figure 1: Schematic diagram of double laser beam cutting optical path system.

2.2 Experimental methods

The laser cutting experiment scene diagram is shown in Figure 2. The figure also shows a roller pressure device was developed to guarantee the regularities of the tobacco slices during laser cutting and flow assistance was introduced to absorb the fumes of the burning tobacco slices, which could protect the focusing lens. The moisture content of the tobacco slice was 13%, and the target cutting shape of the tobacco slice was a square with a side length of 2 cm as shown in Figure 3. To ensure the accuracy of the cutting experiments, each cutting condition of the tobacco slice is repeated three times.

Table 1: Optical parameters of laser system

Parameter	Wavelength (μm)	Output power (W)	Mode quality (M^2)	Beam diameter at lens $1/e^2$ (mm)	Focal length (mm)
Value	10.6 ± 0.4	≥250	<1.2	8.5 ± 1.0	470

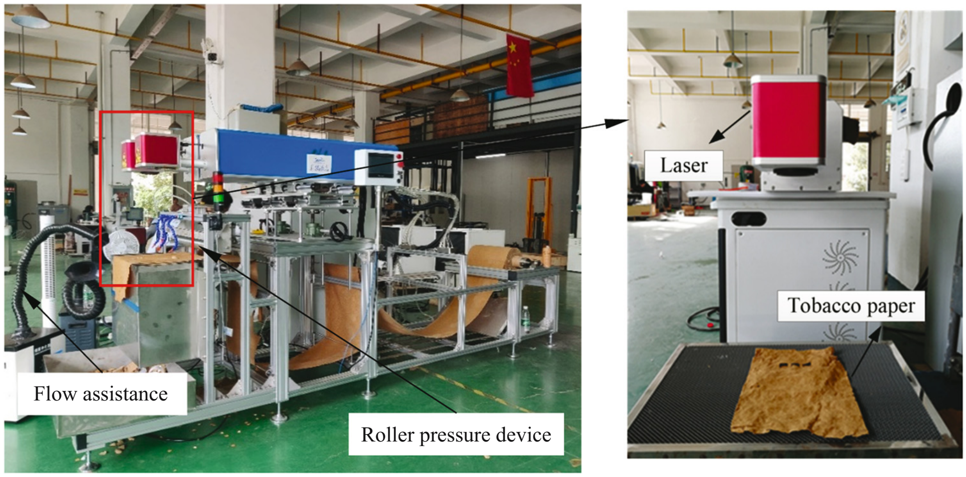

Figure 2: Scene diagram of laser cutting tobacco experiment.

In order to evaluate the laser cutting quality, an optical microscope (Leica Microsystems RH-2000) was used to examine the cross-section of the cutting surface of the tobacco slice.

3 Results and discussion

3.1 Effect of cutting powers and speeds

The laser cutting process of tobacco slices is a process of thermal and chemical decomposition of materials. The tobacco slices are instantly vaporized under the action of high-energy-density lasers to achieve the purpose of cutting. When the laser power is relatively low, the irradiation time increases, and the heat-affected zone increases, causing the tobacco slice to be uneven and difficult to cut. When the laser power is high, the incident laser beam can easily make the material instantly vaporize, resulting in the heat-affected zone being significantly reduced. Finally, the tobacco sheet is cut and smoothed to meet the quality requirements. Thus, it is necessary to study the optimal cutting power for tobacco slices. Cutting speed is another factor that affects cutting efficiency and cutting quality. Figures 4–8 show the cutting morphology of tobacco slices under different cutting powers and speeds. The cutting power is varied from 150 to 350 W with an increment of 50 W while the cutting speed is varied from 1 to 3 m/s with an increment of 0.5 m/s. Figure 4 shows that the cutting marks on the edge of the tobacco slice are getting

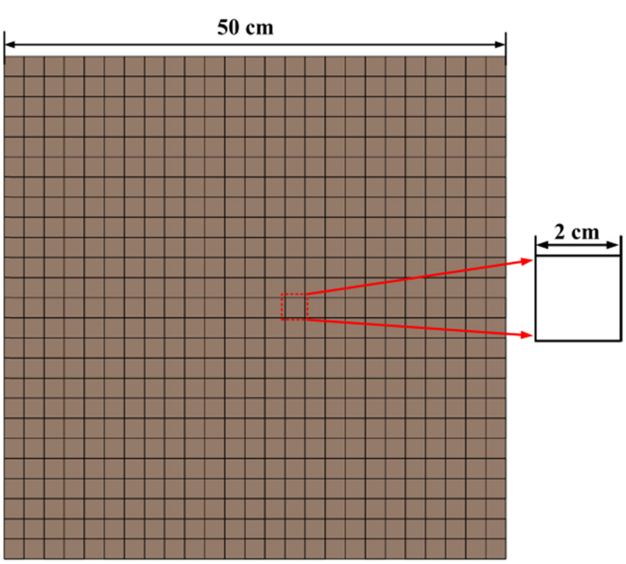

Figure 3: Schematic diagram of target cutting shape of tobacco slice.

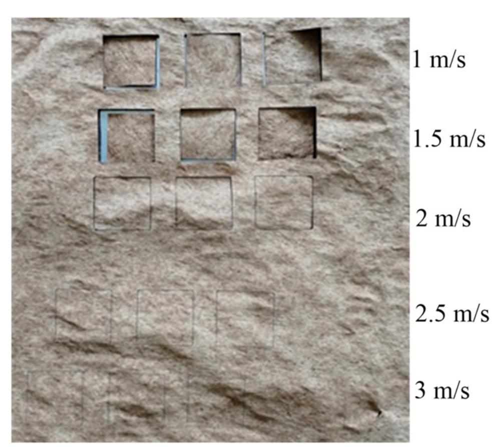

Figure 4: Cutting morphology of tobacco slices under different cutting speeds at a cutting power of 150 W.

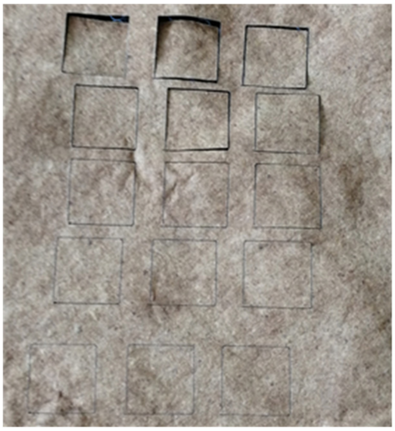

Figure 5: Cutting morphology of tobacco slices under different cutting speeds at a cutting power of 200 W.

shallower and shallower as the cutting speed increases from 1 to 3 m/s at a cutting power of 150 W, which means that the lower cutting speed is more conducive to cutting of tobacco slice. The edges of the tobacco slice are not completely cut through at the cutting speed of 2–3 m/s. The lower the cutting speed, the more fully the tobacco slice can be cut. This is because the decrease in cutting speed increases the interaction time between laser and tobacco slice. And similar phenomenon can be found in Figures 5–8. However, the corresponding work efficiency is also reduced while the cutting speed decreases. Therefore, it is necessary to optimize other process parameters such as cutting power to ensure the cutting efficiency as well as cutting quality of tobacco slices.

Upon comparing Figures 5–8, it shows that the cutting marks on the edge of the tobacco slice are getting deeper and deeper as the cutting power increases from 150 to 350 W at a cutting speed of 2 m/s, which means

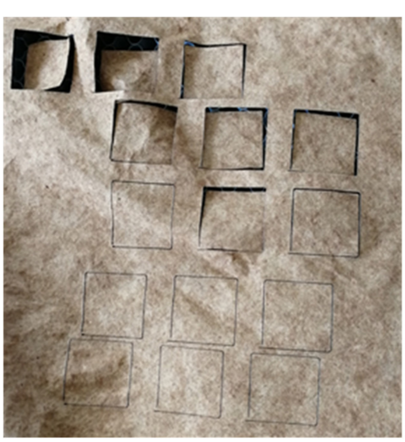

Figure 6: Cutting morphology of tobacco slices under different cutting speeds at a cutting power of 250 W.

Figure 7: Cutting morphology of tobacco slices under different cutting speeds at a cutting power of 300 W.

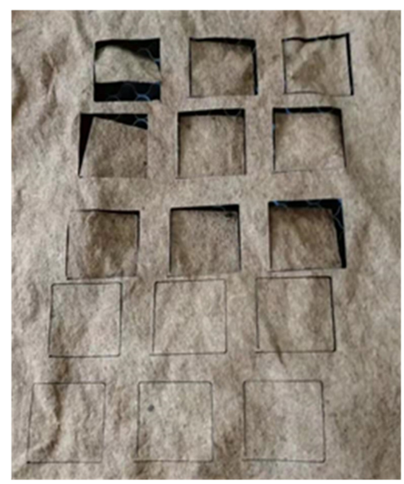

Figure 8: Cutting morphology of tobacco slices under different cutting speeds at a cutting power of 350 W.

Table 2: Laser cutting quality tobacco slices at different powers and speeds

Cutting speed (m/s)	Cutting power (W)				
	150	200	250	300	350
1	+	+	+	+	+
1.5	+	+	+	+	+
2	–	–	+	+	+
2.5	–	–	–	–	+
3	–	–	–	–	–

Note: + means the tobacco slice through while – denotes the tobacco slice is not cut through.

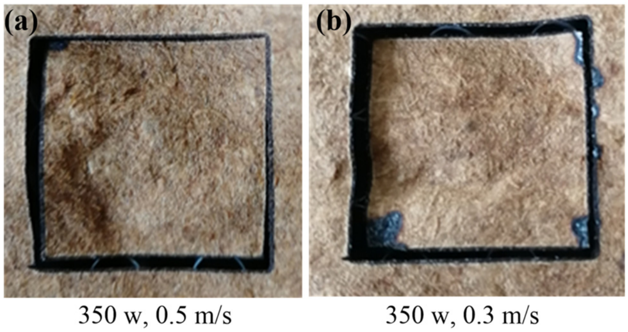

Figure 9: Cutting morphology of tobacco slices with a cutting power of 350 w at cutting speeds of 0.3 and 0.5 m/s.

that higher cutting power is more conducive to cutting of tobacco slice. And similar phenomenon can be found at other cutting speeds as the cutting power varies. In addition, Figures 5–8 show that the tobacco sheet is basically not cut through when the cutting speed is greater than 2.5 m/s, and the cutting quality is poor under all cutting powers. Thus, cutting speeds less than 2.5 m/s are preferable to the cutting of tobacco slices.

The cutting qualities of tobacco slices at different cutting powers and speeds are summarized in Table 2. "+" means the tobacco slices are cut through while "–" denotes the tobacco slices are not cut through. It can be clearly seen from Table 1 that the lower the cutting speed, the more conducive to the cutting of tobacco slices. Meanwhile, the larger the cutting power, the more beneficial the cutting of tobacco slices. However, lower cutting speed means lower cutting efficiency while larger cutting power means larger energy consumption and higher requirements for the laser. Therefore, there is a compromise between cutting speed and cutting power. And the "+" area in Table 2 corresponds to the range of cutting power and speed parameters that can be selected. From Table 2, it can be found that the lowest energy level of completed cutting of tobacco slices ranges from 100 to 150 J/m, when the cutting power increases from 150 to 350 W. Compared with the studies of Stepanov *et al.* [19] and Happonen *et al.* [20], the lowest energy level of completed cutting of tobacco slices is larger than that of common paper materials because of the higher fiber content of tobacco slices.

In order to further explore the critical burning state of tobacco slices when being cut, Figure 9 shows the cutting morphology of tobacco slices with the cutting power of

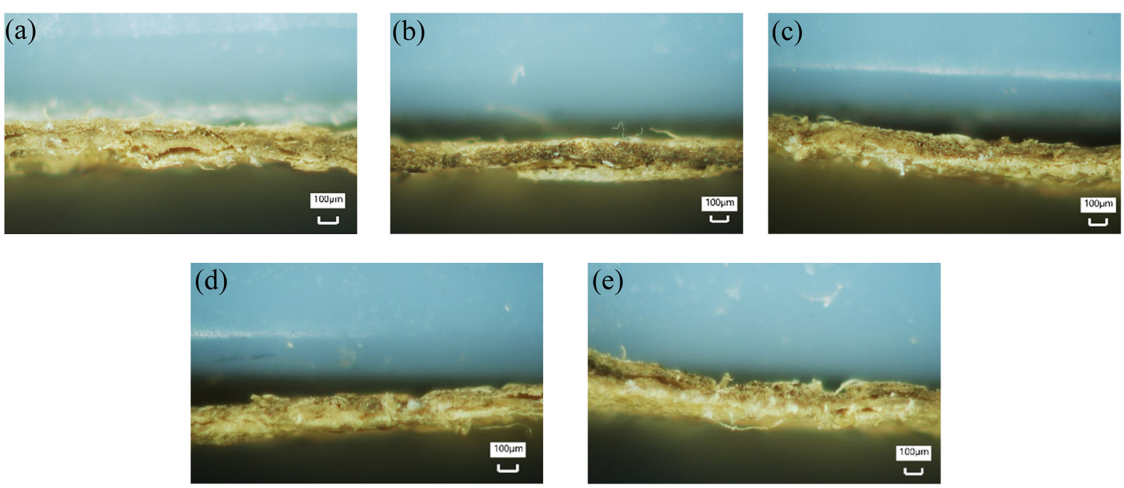

Figure 10: Cross-sectional micrographs of the laser cutting surface of tobacco slice at a cutting speed of 1.5 m/s with different cutting powers: (a) 150 W, (b) 200 W, (c) 250 W, (d) 300 W, and (e) 350 W.

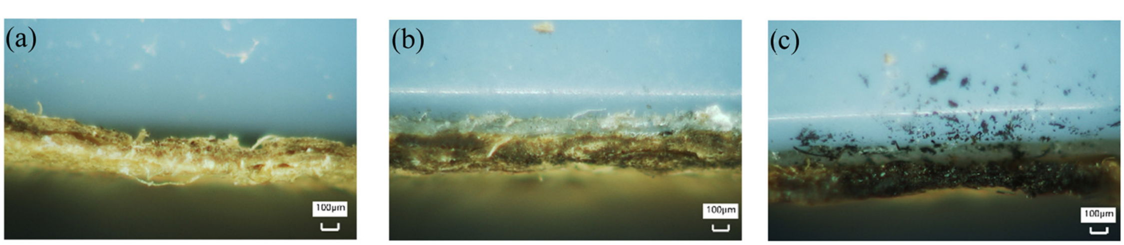

Figure 11: Cross-sectional micrographs of the laser cutting surface of tobacco slice at a cutting power of 350 W with different cutting speeds: (a) 1.5 m/s, (b) 0.5 m/s, and (c) 0.3 m/s.

350 W at cutting speeds of 0.3 and 0.5 m/s. The tobacco slice is slightly burnt during the cutting process at the cutting speed of 0.5 m/s as shown in Figure 9(a). As the cutting speed is further decreased to 0.3 m/s, the tobacco slice is burned more severely as shown in Figure 9(b). This means that the tobacco slice may be scorched when the cutting speed is slow enough, which should be avoided in the actual process.

3.2 Characteristics of cutting surface of tobacco slice

In order to further evaluate the laser cutting quality, the cross-sectional micrographs of cutting surface of tobacco slice are investigated and presented in Figures 10 and 11. As shown in Figure 10, all the cutting surfaces of tobacco slices are relatively smooth and no burnt edge can be found on the cutting surface. Only a little number of sticking out fibers are observed on the cutting surface, because of the large fiber content and uneven fiber distribution of tobacco slices. It indicates that the tobacco slices can directly evaporate when cutting speed of 1.5 m/s and cutting power ranging from 150 to 350 W (cutting energy level ranging from 100 to 233 J/m), resulting in good cutting quality. For studying the largest cutting energy level, the cross-sectional micrographs of the cutting surface of tobacco slices at the high cutting power of 350 W with different cutting speeds are investigated and presented in Figure 11. Obviously, the burning degree of tobacco slice increases with the decrease in the cutting speed, corresponding to the increase in cutting energy level. At the cutting speed of 1.5 m/s (cutting energy level of 233 J/m), a good cutting edge of tobacco slice can be found, without any burning zone. When the cutting speed decreases to 0.5 m/s (cutting energy level of 700 J/m), slightly black tissue appears on the cutting surface. When the cutting speed further decreases to 0.3 m/s (cutting energy level of 1,166 J/m), clearly black tissue is presented on the cutting surface, indicating the serious burning of the cutting edge. All in all, the excellent laser cutting quality of tobacco slice can be obtained, when choosing appropriate cutting parameters.

4 Conclusion

A CO_2 laser is used to study the cutting of tobacco slices. The effects of cutting power and cutting speed on the cutting quality of tobacco slices are investigated. We find that the lower the cutting speed, the more the conducive to the cutting of tobacco slices. And cutting speeds less than 2.5 m/s are preferable to the cutting of tobacco slices. Meanwhile, the larger the cutting power, the more the conducive to the cutting of tobacco slices. However, lower cutting speed means lower cutting efficiency while larger cutting power means larger energy consumption and higher requirements for the laser. To search for the compromise between cutting speed and cutting power, the preferable cutting power and speed parameters are summarized. The results obtained provide practical guidance for cutting high-quality tobacco slices.

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