OPTIMIZATION OF LASER CUTTING PARAMETERS FOR INCREASED CUTTING SPEED IN STAINLESS STEEL

Lukas Brundza[1], Mindaugas Gedvilas[1]

[1]Department of Laser Technologies (LTS), Center for Physical Sciences and Technology (FTMC), Savanorių Ave. 231, 02300 Vilnius, Lithuania
lukas.brundza@ftmc.lt

Laser cutting of thin stainless-steel sheets is widely employed in industry due to its precision and versatility. A key factor in process efficiency is the achievable cutting speed. Recently, a theoretical model was proposed to predict the maximum scanning speed for through-cutting thin materials, providing an explicit relationship between cutting speed, material properties, and laser parameters. While substantial progress has been made in optimizing ablation efficiency [1-8], achieving high cutting speeds in thin metal sheets remains challenging despite recent theoretical advances [9]. In this work, we refine the model by introducing adjustments to the critical speed equations that account for specific laser and material parameters, thereby extending its predictive capability. Building on this framework, we experimentally validate the model for stainless-steel sheets and identify the optimal cutting speed under practical conditions. Furthermore, we compare nanosecond and picosecond laser sources, analyzing their respective advantages and limitations for stainless-steel cutting. The results demonstrate the practical applicability of the improved theoretical model while also revealing distinct performance trade-offs between different pulse duration regimes.

Laser irradiation with a central wavelength of 1064 nm, controllable pulse durations of 4.5 ns or 13 ps, and a repetition rate of 400 kHz was used in the experiments. We determined that the maximum cutting speeds were 31 mm/s for nanosecond pulses at an average laser power of 38 W and 14 mm/s for picosecond pulses at an average laser power of 44 W for stainless steel sheets with a thickness of 0.3 mm at certain optimal fluence values using a slightly defocused Gaussian beam. The beam size optimization theoretical approach was adopted from [9] to explain the experimental data. These results will be valuable for industries requiring high-precision microfabrication, such as electronics, automotive, and medical device manufacturing, where speed and accuracy are most critical.

[1] G. Raciukaitis, “Use of high repetition rate and high power lasers in microfabrication: how to keep the efficiency high?,” Journal of Laser Micro/Nanoengineering, vol. 4, no. 3, pp. 186–191, Dec. 2009, doi: 10.2961/jlmn.2009.03.0008.
[2] A. Žemaitis, M. Gaidys, M. Brikas, P. Gečys, G. Račiukaitis, and M. Gedvilas, “Advanced laser scanning for highly-efficient ablation and ultrafast surface structuring: experiment and model,” Scientific Reports, vol. 8, no. 1, p. 17376, Nov. 2018, doi: 10.1038/s41598-018-35604-z.
[3] A. Žemaitis, M. Gaidys, P. Gečys, G. Račiukaitis, and M. Gedvilas, “Rapid high-quality 3D micro-machining by optimised efficient ultrashort laser ablation,” Optics and Lasers in Engineering, vol. 114, pp. 83–89, Nov. 2018, doi: 10.1016/j.optlaseng.2018.11.001.
[4] A. Žemaitis, P. Gečys, M. Barkauskas, G. Račiukaitis, and M. Gedvilas, “Highly-efficient laser ablation of copper by bursts of ultrashort tuneable (fs-ps) pulses,” Scientific Reports, vol. 9, no. 1, p. 12280, Aug. 2019, doi: 10.1038/s41598-019-48779-w.
[5] M. Gaidys, A. Žemaitis, P. Gečys, and M. Gedvilas, “Efficient picosecond laser ablation of copper cylinders,” Applied Surface Science, vol. 483, pp. 962–966, Apr. 2019, doi: 10.1016/j.apsusc.2019.04.002.
[6] A. Žemaitis, M. Gaidys, P. Gečys, M. Barkauskas, and M. Gedvilas, “Femtosecond laser ablation by bibursts in the MHz and GHz pulse repetition rates,” Optics Express, vol. 29, no. 5, p. 7641, Feb. 2021, doi: 10.1364/oe.417883.
[7] A. Žemaitis, M. Gaidys, P. Gečys, and M. Gedvilas, “Bi-stability in femtosecond laser ablation by MHz bursts,” Scientific Reports, vol. 14, no. 1, p. 5614, Mar. 2024, doi: 10.1038/s41598-024-54928-7.
[8] A. Žemaitis, U. Gudauskytė, S. Steponavičiūtė, P. Gečys, and M. Gedvilas, “The ultrafast burst laser ablation of metals: Speed and quality come together,” Optics & Laser Technology, vol. 180, p. 111458, Jul. 2024, doi: 10.1016/j.optlastec.2024.111458.
[9] X. Du and X. Yu, “Maximizing scanning speed in the ultrafast laser cutting of thin materials,” Optics Express, vol. 31, no. 6, p. 9750, Feb. 2023, doi: 10.1364/oe.478214.