Optics and Lasers in Engineering 100 (2018) 82–89

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

Dynamic laser piercing of thick section metals

Jetro Pocorni[a,*], John Powell[a,b], Jan Frostevarg[a], Alexander F.H. Kaplan[a]

[a] *Department of Engineering Sciences and Mathematics, Luleå University of Technology, 971 87 Luleå, Sweden*
[b] *Laser Expertise Ltd., Acorn Park Industrial Estate, Harrimans Lane, Nottingham NG7 2TR, UK*

ARTICLE INFO

Keywords:
Laser cutting
Laser piercing
Reliability
Efficiency
Fibre laser
High speed imaging

ABSTRACT

Before a contour can be laser cut the laser first needs to pierce the material. The time taken to achieve piercing should be minimised to optimise productivity. One important aspect of laser piercing is the reliability of the process because industrial laser cutting machines are programmed for the minimum reliable pierce time. In this work piercing experiments were carried out in 15 mm thick stainless steel sheets, comparing a stationary laser and a laser which moves along a circular trajectory with varying processing speeds. Results show that circular piercing can decrease the pierce duration by almost half compared to stationary piercing. High speed imaging (HSI) was employed during the piercing process to understand melt behaviour inside the pierce hole. HSI videos show that circular rotation of the laser beam forces melt to eject in opposite direction of the beam movement, while in stationary piercing the melt ejects less efficiently in random directions out of the hole.

1. Introduction

Although metal sheet laser cutting is a well-established process [1–4], research is still being carried out to optimize the technology, especially since the introduction of fibre lasers (see e.g. Petring et al. [5] and Pocorni et al. [6,7]) and direct diode lasers (Rodrigues et al. [8]). One aspect of laser cutting which has received little scientific attention is the piercing event which precedes nearly every laser cutting operation. Almost all laser cutting operations involve a piercing operation before cutting can commence. Fig. 1(a) demonstrates that the pierce hole is located off of the cut path. Piercing involves drilling a hole in the material to be cut in order to establish a cut front which will allow laser energy to enter at the top of the cut zone, and molten material to flow from the bottom. Piercing differs from the cutting process in that any melt must be removed by ejection from the top of the work piece rather than the bottom, as described by Hashemzadeh et al. [9], see Fig. 1(b). Also, during piercing, the heat flows away from the laser-material interaction zone in three dimensions, whereas heat flow from a cut zone is essentially two dimensional.

The authors [10] previously studied piercing by comparing penetration times obtained with the laser in the pulsed and continuous wave (CW) mode. The present paper is a continuation of this work and compares piercing with a beam moving along a circular trajectory to stationary piercing. Ohlsson et al. (1992) [11] introduced a piercing technique where an abrasive waterjet moves along a circular trajectory. They found that for 15 mm thick mild steel, the circular movement technique decreased the piercing time by a factor of 8 compared to piercing with a stationary waterjet. They showed that high velocity abrasive particles from the moving jet impinge on the work piece at a glancing angle, creating an erosion zone with directional flow which is more efficient than the one formed at the bottom of a hole created by a stationary jet. Fig. 2 shows a schematic of this type of 'moving jet' piercing using a laser beam instead of an incident waterjet.

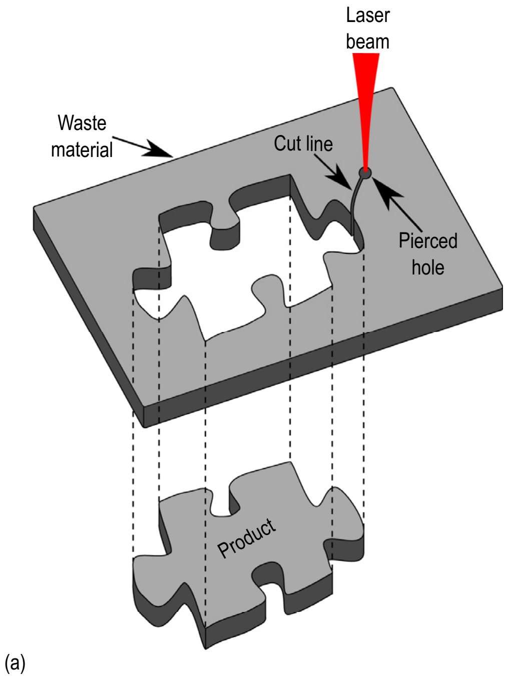
Piercing has some similarities to laser drilling [12–17]. In both piercing and drilling a hole is generated by ejecting molten material back through the hole entrance until breakthrough occurs, after which molten material can exit through the bottom of the hole. Fig. 1(b) shows a schematic of the stationary piercing process. Some vaporisation occurs, and the recoil pressure generated can aid expulsion of molten material. Drilling and piercing usually result in resolidified material lining the hole (Voisey et al. [12]) and the generation of heat affected zones (Österle et al. [13]) and surface spatter (Low et al. [14]). However, laser drilling is generally carried out to generate functional holes with specific high tolerance geometries and there is therefore a considerable amount of interest in quality control and reproducibility (Leigh et al. [15]). Hashemzadeh et al. [9] point out that in piercing only the hole diameter, time of penetration and the reliability of the piercing time are of practical interest.

Wolff et al. (2016) [18] applied a so-called 'pulsed spiral drilling' method during which power, duty cycle, frequency, nozzle distance and gas pressure were adjustable. They were able to laser pierce 20 mm mild steel in less than 8000 ms with an entrance hole diameter of 800 µm. By applying an initial high power laser pulse of approximately 100–150 ms duration the pierce time was reduced by 30% but the entrance hole

---

[*] Corresponding author.
E-mail addresses: Jetro.Pocorni@ltu.se, Jetro.Pocorni@yahoo.com (J. Pocorni).

http://dx.doi.org/10.1016/j.optlaseng.2017.07.012
Received 21 February 2017; Received in revised form 5 June 2017; Accepted 26 July 2017



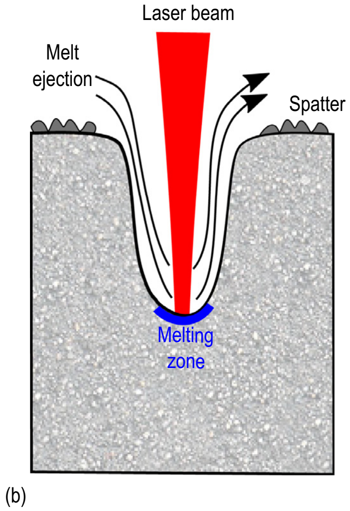


Fig. 1. (a) Laser piercing occurs before and off the cut path; (b) the stationary laser piercing process.

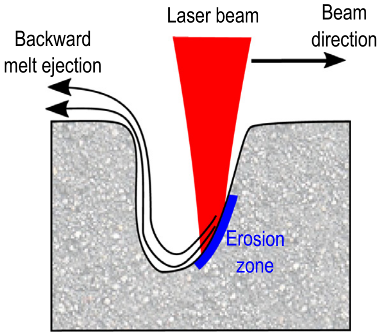


Fig. 2. Cross section of pierce hole in circular movement piercing along propagation direction of laser beam.

diameter increased to 4775 µm. They were also able to decrease the piercing duration further down to 1000 ms by increasing the pressure of the processing oxygen gas; consequently, the hole quality deteriorated (melt blow outs and increased hole diameters were reported). However, the piercing of mild steel with a laser in conjunction with an oxygen jet involves a vigorous oxidation reaction and is a different process than the stainless steel – nitrogen piercing which is investigated in this present work.

Hashemzadeh et al. [9] and Rao et al. [19] used a CW mode for their laser piercing experiments while Rao et al. [20] carried out laser drilling with a pulsed mode laser with high duty cycle. Rao et al. [20] show that the piercing time and hole diameter can be affected by a number of process parameters including laser wavelength, peak power, power modulation and process gas type and pressure.

This present work is an experimental study which uses High Speed Imaging (HSI). HSI observation of laser cutting spans almost 40 years and includes work done by Arai [21], Arata et al. [22,23], Ermolaev et al. [24], Hirano and Fabbro [25], Petring et al. [5], Pocorni et al. [26,27], Riveiro et al. [28], and Zefferer et al. [29]. However, high speed imaging (HSI) recordings of laser piercing have only recently been published by Pocorni et al. (2017) [10]. Laser drilling, on the other hand, has been extensively studied by HSI and optical observation in the past [30–36].

Melt ejection can be made more efficient if the gas jet has a flow path into and out of the partially penetrated hole. For this to be the case the piercing zone needs to be elongated to make the interaction between the gas jet and the melt asymmetrical, as shown in Fig. 2. Moving the beam provides this elongation but, in turn, increases the laser-material interaction zone volume.

If the laser beam is moved in a straight line this increase in volume would also be associated with more effective conductive cooling as the beam moves from heated areas to cooler material. An asymmetrical piercing event can, however, also be created by moving the beam in a small circle and this also minimises heat wastage because the interaction zone remains in a restricted, heated area.

In this paper various combinations of the circular trajectory diameter and beam processing velocity were applied to find a minimum pierce time. HSI was used to investigate flow characteristics within the pierced hole and to time the penetration event of circular movement and stationary piercing techniques. The piercing process in this study was carried out in 15 mm thick stainless steel with a continuous wave (CW) output.

2. Experimental method

The piercing experiments were carried out with an Ytterbium fibre laser (15 kW maximum output laser power, 1070 nm wavelength, manufacturer IPG Laser, type YLR-15,000). The laser beam was delivered through a 400 µm optical fibre to a Precitec laser cutting head which employed a 125 mm focal length lens (Collimator: 100 mm, magnification 1.25:1). All piercing experiments were performed in 15 mm thick stainless steel sheet (SIS 2333) in the 'as received' surface condition.

In the present study, piercing with a moving beam along a circular trajectory was compared to stationary laser beam piercing. A schematic of stationary piercing is shown in Fig. 1(b) and circular movement piercing is presented in Fig. 3(a).

In the case of circular movement piercing, two parameters are of importance; the diameter of the circular trajectory *D* and the velocity of the beam movement *v*. The diameter of the circular trajectory was controlled by an Isel EuroMod CNC workstation. In Fig. 3(b) the dimensions relevant to the circular movement are shown.

The gas nozzle had a diameter of 3.5 mm, nitrogen gas was supplied to the nozzle at a pressure of 7 bar, and the standoff distance between the nozzle and the work piece was set to 6 mm. The laser beam was focused 6 mm below the work piece surface. The laser beam spot diameter at the surface was 700 µm.