Optics and Lasers in Engineering 55 (2014) 143–149

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

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

Fibre laser piercing of mild steel – The effects of power intensity, gas type and pressure

M. Hashemzadeh [a], J. Powell [b], K.T. Voisey [a,*]

[a] Materials, Mechanics and Structures Research Division, Faculty of Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, UK
[b] Deptartment of Engineering Sciences and Mathematics, Lulea University of Technology. SE-971 87 Lulea, Sweden

ARTICLE INFO

Article history:
Received 19 December 2012
Received in revised form
16 August 2013
Accepted 1 October 2013
Available online 21 November 2013

Keywords:
Laser piercing
Laser cutting
Mild steel
Fiber laser
Fibre laser

ABSTRACT

Laser piercing is used to generate a starting point for laser cutting. The pierced hole is normally larger than the kerf width, which means that it cannot lie on the cut line. An experimental programme investigating the piercing process as a function of laser and assist gas parameters is presented. An Nd:YAG fibre laser with a maximum power of 2 kW was used in continuous wave mode to pierce holes in 2 mm thick mild steel. Oxygen and nitrogen were used as assist gases, with pressures ranging from 0.3 to 12 bar. The sizes, geometries and piercing time of the holes produced have been analysed. The pierced hole size decreases with increasing gas pressure and increasing laser power. Oxygen assist gas produced larger diameter holes than nitrogen. A new technique is presented which produces pierced holes no larger than the kerf with and would allow the pierced hole to lie on the cut line of the finished product – allowing better material usage. This uses an inclined jet of nitrogen when piercing prior to oxygen assisted cutting.

1. Introduction

Laser cutting of sheet metal is widely used in industry. The process basically consists of the laser melting material which is then expelled through the bottom of the cut kerf by the action of a gas jet. Oxygen is often employed as the assist gas when cutting mild steel as it adds energy to the process via the exothermic oxidation of iron.

Cuts do not generally start from the free edge of a sheet and so a hole needs to be pierced from which the laser cut can begin. This is usually simply done by holding the laser beam stationary at the start of the cut until a through-hole is pierced. Subsequent motion of the laser with respect to this point then generates the cut. It is the initial piercing operation that is of interest to the current work.

As illustrated in Fig. 1, the diameter of the initial pierced hole generally exceeds the kerf width of the cut. It is therefore normal practice for the initial pierced hole site to be positioned off of the final cut edge, as shown in Fig. 2. This optimises the quality of the cut but also results in some material wastage. The ideal case would be for the diameter of the initial pierced hole to match the kerf width. There would then be no need for the pierced hole to lie off of the final cut line which would result in two benefits; a. cut parts could be placed closer together on the sheet, saving material, b. the cut line from the pierce hole to the required profile would not be necessary, reducing the process time.

As piercing is the initial step of the cutting process it might be assumed that the physics of piercing would be similar to that of cutting – but in fact the two phenomena are quite different. The main difference is the direction of fluid flow of the melt created – towards the laser in the case of piercing, and away from the laser during cutting.

Laser piercing has several similarities to, but also some important differences from, laser drilling. Both methods generate a hole by ejecting molten material back through the hole entrance until breakthrough (Fig. 3), after which molten material can exit through the bottom of the hole [1]. Some vaporisation occurs, and the recoil pressure generated can aid expulsion of molten material. Both processes usually result in resolidified material lining the hole [1] and the generation of heat affected zones [2] and surface spatter [3]. However, laser drilling is usually carried out using pulsed lasers; whereas continuous wave irradiation is often used for piercing. Laser drilling is generally done to generate functional holes with specific high tolerance geometries and dimensions, there is therefore a considerable amount of interest in quality control and reproducibility [4]. In piercing only the hole diameter and time of penetration are of practical interest.

A significant amount of work has been done on understanding how process parameters affect laser drilling [5–10]. The laser drilling that is closest to the laser piercing work here is laser drilling of metallic materials several millimetres in thickness using Nd:YAG lasers with pulse lengths of the order of milliseconds and pulse

* Corresponding author. Tel.: +44 115 951 4139.
E-mail address: katy.voisey@nottingham.ac.uk (K.T. Voisey).

0143-8166/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.optlaseng.2013.10.001

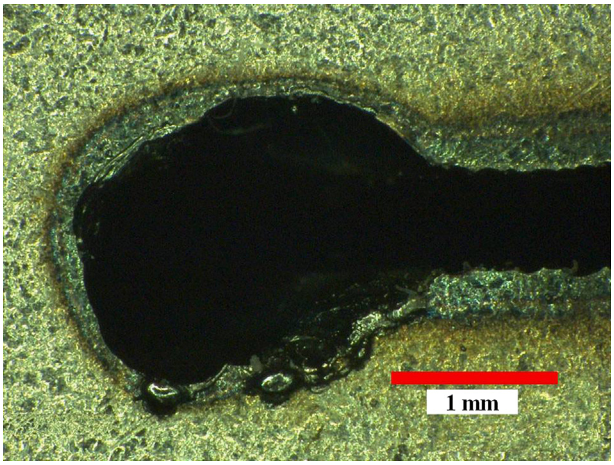

Fig. 1. A pierced hole at the start of a laser cut in 2 mm thick mild steel using 1000 W, 2 bar oxygen. The piercing hole is usually considerably wider than the kerf width (the kerf is shown here on the right hand side of the figure).

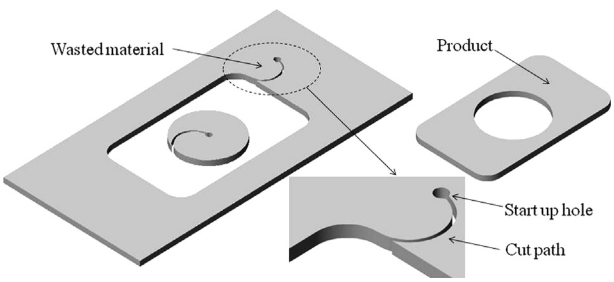

Fig. 2. Illustrating how locating the initial pierced hole off of cut path wastes material and time.

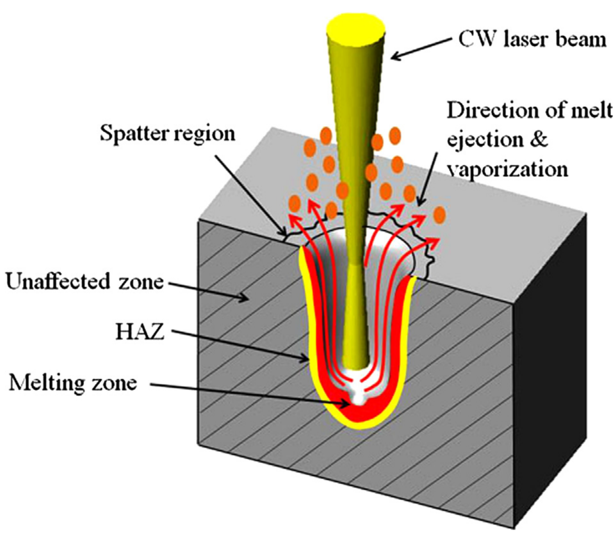

Fig. 3. The laser piercing process.

energies of a few joules. In such laser drilling material removal occurs primarily via melt ejection [1,3,5–11]. It is well known that assist gas pressure affects hole shape and dimensions [11], with an increase in assist gas pressure normally enhancing the melt ejection process, decreasing the time required for drilling. As for laser cutting [12], the use of oxygen as an assist gas enhances the drilling process since the exothermic oxidation reaction acts as an additional heat source. For the conditions and laser wavelength used in this work laser-plasma effects are not expected to be significant [13].

The piercing time and hole diameter can be affected by a number of process parameters including laser wavelength, power, power modulation and assist gas type and pressure [14]. This paper presents the results of a detailed systematic study of piercing 2 mm thick mild steel sheet using a fibre laser in its continuous wave mode and oxygen or nitrogen as the assist gas. In piercing, the presence of oxygen in the melting zone generates additional heat from the exothermic oxidation reaction and also produces a relatively low viscosity oxidised melt [12,15].

Whilst there is extensive published literature on laser cutting and laser drilling, there is little on the laser piercing process. This work aims to investigate the piercing process as a function of irradiation time, assist gas type and pressure. The ultimate objective is to use the understanding thus gained in order to minimise the dimensions of the pierce hole, ideally making it no larger than the kerf width, thereby decreasing material wastage.

2. Experimental method

2.1. Material

A 2 mm thick cold rolled mild steel was utilised in this work. The chemical composition, as determined by spark emission, is given in Table 1.

2.2. Laser

An IPG YLR-2000 multimode Nd:YAG 2 kW, 1.06 μm wavelength fibre laser was used in the continuous wave mode. Powers in the range of 600–1400 W were used. The laser beam was delivered into the cutting head by a 200 μm diameter optical fibre. This was focussed by a 120 mm focal length lens into a spot with a diameter of 206 μm. Throughout the work the focal position was on the top surface of the sample, the focus did not move with respect to its original position as the hole progressed. A 1 mm diameter nozzle was used to deliver the assist gas coaxially to the laser beam, the standoff distance between nozzle and sample surface was 1 mm.

Nitrogen and oxygen were used as assist gases over a range of pressures from 0.3 bar to 12 bar.

Table 2 details the parameters used. It should be noted that the laser was only on for the times stated, however the assist gas continued to flow for some time after the laser had been turned off. For each parameter setting five holes were pierced and the results presented are the average values.

Table 1
Chemical composition of the mild steel (wt%).

C	Si	Mn	P	S	Cr	Mo	Ni	Al
0.03	0.005	0.192	0.003	0.015	0.023	0.005	0.013	0.034

Table 2
Piercing parameters used.

Assist gas		Laser power/W						
Gas	Pressure/bar	600	800	1000	1200	1400	1700	2000
N_2	0.3	X	X	X	X	X		
N_2	2			X	X	X	X	X
N_2	3					X	X	X
N_2	8					X	X	X
N_2	12					X	X	X
O_2	0.3	X	X	X	X	X	X	X
O_2	2	X	X	X	X	X	X	X
O_2	4					X	X	X
O_2	8					X	X	X