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Fibre laser cutting stainless steel: Fluid dynamics and cut front morphology

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ABSTRACT

In this paper the morphology of the laser cut front generated by fibre lasers was investigated by observation of the ‘frozen’ cut front, additionally high speed imaging (HSI) was employed to study the fluid dynamics on the cut front while cutting. During laser cutting the morphology and flow properties of the melt film on the cut front affect cut quality parameters such as cut edge roughness and dross (residual melt attached to the bottom of the cut edge). HSI observation of melt flow down a laser cutting front using standard cutting parameters is experimentally problematic because the cut front is narrow and surrounded by the kerf walls. To compensate for this, artificial parameters are usually chosen to obtain wide cut fronts which are unrepresentative of the actual industrial process. This paper presents a new experimental cutting geometry which permits HSI of the laser cut front using standard, commercial parameters. These results suggest that the cut front produced when cutting medium section (10 mm thick) stainless steel with a fibre laser and a nitrogen assist gas is covered in humps which themselves are covered by a thin layer of liquid. HSI observation and theoretical analysis reveal that under these conditions the humps move down the cut front at an average speed of approximately 0.4 m/s while the covering liquid flows at an average speed of approximately 1.1 m/s, with an average melt depth at the bottom of the cut zone of approximately 0.17 mm.

1. Introduction

Laser cutting is a well-established industrial process and has now become a multibillion euro industry. A wide range of materials can be processed by laser cutting, from polymeric materials (Choudhury et al. [1]) to tool steels (Scintilla et al. [2]) and Nickel super alloys (Hasçalık et al. [3]). In depth research into the details of the process is continuing to optimise cutting speeds and cut edge quality.

In laser fusion cutting of metals a volume of melt is created (by absorption of the laser beam) and then blown out of the cut zone by an inert assist gas. During the process a thin layer of melt flows down the cut front, as shown in Fig. 1.

The importance of understanding the melt flow on the cut front is discussed by Tani [5] who states that both the amount of dross at the bottom of the kerf and the cut edge surface roughness depend on the melt film condition throughout the kerf. Schulz et al. [6] have also pointed out that dross formation is related to properties of the melt such as its thickness and velocity.

The importance of the melt film characteristics on the cut front is also emphasised by Chen and Yao [7] who conclude that fluctuations in the absorbed laser power and the velocity of the high speed gas jet can create perturbations in the melt film which in turn could give rise to fluctuating striation patterns on the cut edge. Dross and surface roughness are, of course, important because they are two of the main quality parameters in laser cutting (Rajaram et al. [8] and Ghany et al. [9]). An increase in cut edge roughness has been noted by both Himmer et al. [10] and Purtonen et al. [11] when fibre lasers are used to profile metals of 6 mm thickness and higher. Petring et al. [12,13] have also studied melt flow and kerf morphology and have explained that the decrease in cut edge quality for fibre lasers is primarily due to multiple reflections of the laser beam against the kerf walls.

High speed imaging has been used in the past to investigate the hydrodynamics of the melt layer (Arata et al. [14,15]) and striation formation (Zefferer [16]). Previous work on HSI of the cut front has

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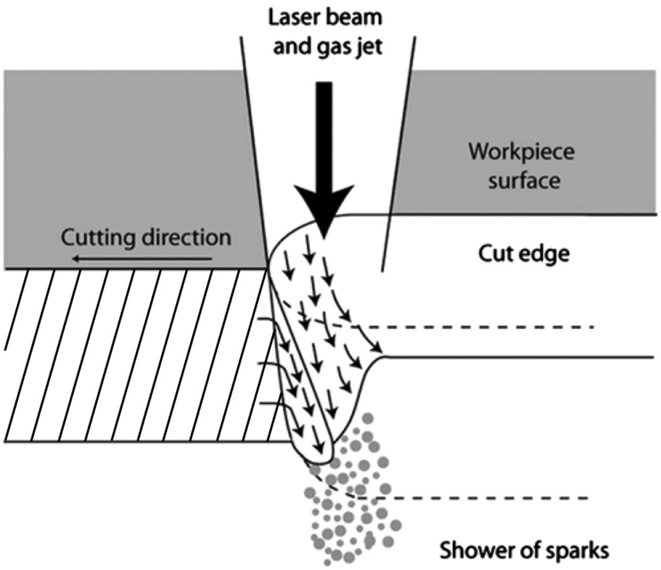

Fig. 1. The laser cutting process (Powell [4]).

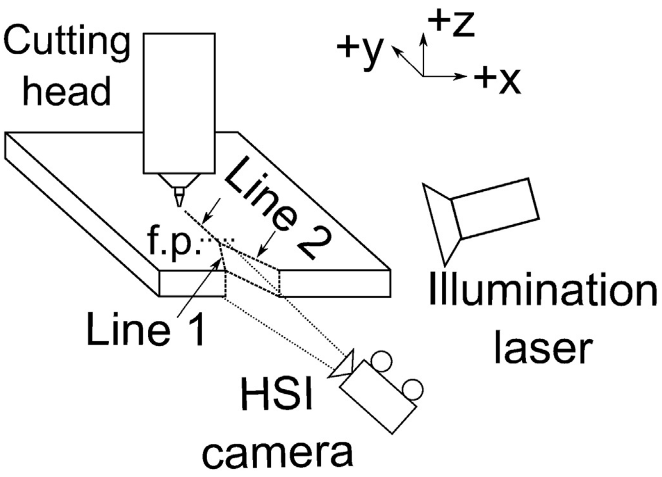

Fig. 2. HSI experimental setup. (f.p. indicates camera focal point.).

Table 1
Cutting and laser beam parameters used.

Parameters	Values
Thickness	10 mm
Cutting speed	1.8 m/min
Laser power	6000 W
Focal position	−12 mm
Gas type	N_2
Gas pressure	16 bar
Nozzle diameter	3.5 mm
Nozzle standoff distance	0.8 mm
Fibre diameter	100 μm
Focusing lens-focus distance	200 mm
Collimation lens-collimation distance	100 mm
Beam focus diameter	200 μm

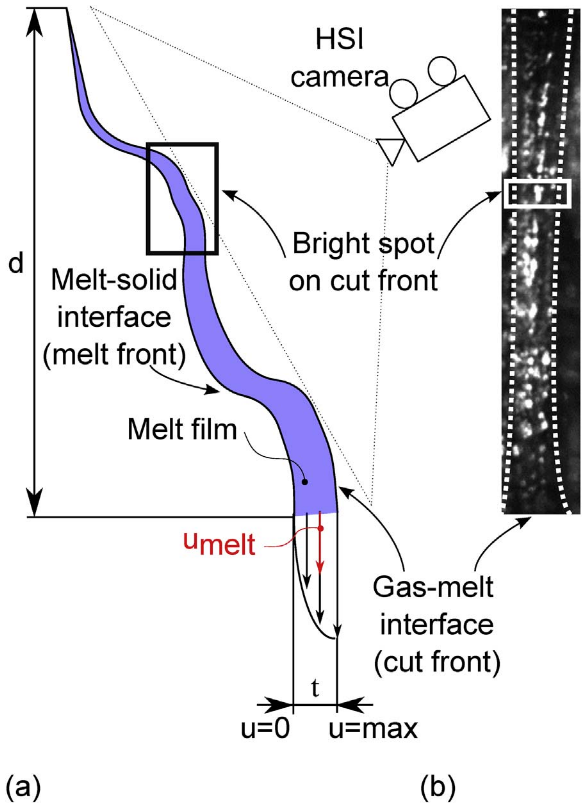

Fig. 3. (a) The HSI set-up and (b) a single frame from the HSI film showing bright spots on the cut front.

been performed either by using unrealistic cut parameters to obtain wide kerfs for camera viewing (Hirano and Fabbro [17]) or by replacing one wall of the cut kerf with a transparent plate and then filming the cut front from the side (Ermolaev et al. [18]).

Others such as Riveiro et al. [19] used transparent silica glass (which strongly absorbs CO_2 radiation) as a work piece. They then filmed the cut front from the side through the glass. It is clearly of interest to observe the melt flow down a metal laser cutting front when using standard cutting parameters and cutting conditions (a narrow cut front surrounded by the recently cut walls of the kerf).

Laser cutting of steels can be divided into two main subjects i.e. laser fusion cutting of stainless steel (usually with nitrogen assist gas) and laser oxygen cutting of mild steel with oxygen gas assist. In both cases the assist gas is used as a source of mechanical energy to blow away the melt in the kerf. In laser oxygen cutting the oxygen assist gas also functions as a source of heat since the oxygen undergoes an exothermic reaction with the iron in mild steel. However, the gas pressures used in the two techniques are markedly different. Oxygen pressures tend to be less than 2 bar and nitrogen pressures are usually in excess of 10 bar. Although oxygen was used to cut both mild and stainless steels in the early days of laser cutting (Powell [20]) only high pressure nitrogen is employed to cut stainless steels nowadays. This paper concerns the flow conditions in the kerf during laser cutting of stainless steel with nitrogen assist gas.

1.1. *Melt flow in laser fusion cutting*

Wandera and Kujanpaa [21] modelled the melt film velocity and corresponding melt thickness and compared this with an experimentally determined position at which the flow inside the cut front becomes turbulent (the so called boundary layer point) for 10 mm stainless steel with a cutting speed of 1 m/min and 5 kW fibre laser. They suggested a melt velocity between 1400 and 2200 m/s with a melt thicknesses of 0.2–0.4 μm for a nitrogen gas pressure between 16–18 bar and kerf width between 600–800 μm.

Hirano and Fabbro [17] investigated the hydrodynamics of the melt layer in laser cutting 3 mm thick mild steel with nitrogen assist gas by using a HSI camera. They found a melt velocity of 3.2 m/s while the velocity of the observed humps was 0.2 m/s. They explain that the difference in velocity is due to the fact that the evolution of the hump is not due to a mass flow but due to a