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ScienceDirect

Physics Procedia 78 (2015) 110 – 119

Physics
Procedia

15th Nordic Laser Materials Processing Conference, Nolamp 15, 25-27 August 2015, Lappeenranta, Finland

Modelling of the Remote Fusion Cutting Process Based on Experiments

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Abstract

Remote fusion cutting (RFC) is an interesting industrial process compared to traditional laser cutting. It is because traditional laser cutting is limiting travel speed and accessibility due to the required positioning of the cutting head just above the workpiece for providing a cutting gas pressure. For RFC this pressure is created by the vapor, which is formed when the laser beam evaporates the cut material. The drawback of RFC compared to traditional laser cutting is a worse cut quality, wide cut kerf and a slower travel speed. The contribution of this paper is an experimental investigation, which determined the process window for RFC in stainless steel with a single mode fiber laser. The process variables: travel speed, focus position, power and sheet thickness were investigated. Based on the results of the experiments and process knowledge the aim of this work was to determine and describe the most important driving mechanisms for understanding and modelling the RFC process. The purpose is to deepen the understanding of the mechanisms in the process and find the factors, which can improve the performance and also determine the limitations. The validation results show that the developed model of the RFC process gives a similar process window as the experimental results for the tested parameters and variation of travel speed and focus position.

Peer-review under responsibility of the Lappeenranta University of Technology (LUT)

Keywords: Laser material processing; cutting process model; single mode fiber laser

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Peer-review under responsibility of the Lappeenranta University of Technology (LUT)
doi:10.1016/j.phpro.2015.11.023

1. Introduction

Remote laser cutting has many advantages as the laser cutting head does not have to follow the surface to cut. These advantages are: increased travel speed, lower risk of tool collision, narrower access path required by the beam than a cutting head and no use of cutting gas. Two different types of remote cutting techniques exist: remote ablation cutting (RAC) and remote fusion cutting (RFC). The melt removal is very distinct for these two processes. RAC is a process, which stepwise over a number of runs evaporates the material and pushes the liquid metal out of the kerf to create a final cut. RFC is also called vapour-pressure fusion cutting due to the mechanisms in the process, where the laser evaporates some of the metal to create a vapour pressure forcing the melt out of the kerf. Pihlava et al. (2013).

Due to the high temperatures (>2000°C) involved in the process and the high process speed (>5000 mm/min) the RFC process is non-trivial to model analytically due to the high temperature gradients and lack of material data for the high temperature area. To overcome this, an empirical approach is taken in this paper. A process window for the RFC process is determined for variation of selected process variables. Based on this process window and analytical equations a basic model is formulated to understand the most important mechanisms in the process. The fit of the model to the experimental data is determined.

Nomenclature

A	Absorptivity defined for laser wavelength λ	0.700	
λ	Laser wavelength [m]	$1.076\cdot10^{-7}$	
K	Thermal conductivity of steel [W/(m·K)]	40	
ρ	Density of steel [kg/m^3]	7850	
Cp	Thermal heat capacity of steel [J/(kg·K)]	690	
κ	Thermal diffusivity of steel [m^2/s]	$6.6253\cdot10^{-6}$	
T_m	Melt temperature of steel [K]	1723	
γ	Surface tension of steel [N/m]	0.56	@1808K
μ	Viscosity of steel [kg/(m·s)]	0.0069	@1808K
V	Travel speed [m/sek.]		
z	Focus position [m]		
S	Sheet thickness [m]		
f_{foc}	Focal length [m]		
D_0	Collimated beam diameter [m]		
D_Z	Beam diameter [m]		
M^2	Beam quality factor		
P	Laser power [W]		
I_{max}	Maximum intensity [W/m^2]		
P_{res}	Resulting pressure [N/m^2]		
P_V	Vapour pressure [N/m^2]		
P_M	Moving pressure [N/m^2]		
P_A	Acceleration pressure [N/m^2]		
P_T	Surface tension pressure [N/m^2]		

1.1. State of the art

Different approaches exist for modelling the RFC process. An analytical model by Matti et al. (2013) calculates the energy balance to model a three-dimensional vaporization front. In a combination with an empirical model the melt flow field is calculated. Mahrle et al. (2010) models the driving mechanisms to calculate the processing speed and need of energy to drive the RFC process.

Numerical computation by finite element analysis has been applied by Otto et al. (2010) and Otto et al. (2011) for RFC. The process is modelled in OpenFOAM and COMSOL. It models the recoil pressure of the evaporation vapor