Analysis of laser cutting process of structural steel

Majid Shamlooei[1,2], Gabriele Zanon[2], Marco brugnolli[3], Alberto Valli[3], Oreste S. Bursi[2]

[1]Department of Information engineering and computer science, University of Trento, Italy

[2]Department of Civil, Environmental and Mechanical Engineering, University of Trento, Italy

[3]BLM Group Adige-Sys, Trento, Italy

Introduction

The laser technology, due to its advantages like high precision and speed, is widely used for material processing such as cutting, welding, additive manufacturing, etc. [1].
Since the laser material processing is a multidisciplinary subject, analysing whole the process from laser itself to substrate material needs to have a wide knowledge of different fields of science and engineering as it is illustrated in Fig. 1.
In this study, thermomechanical analysis of mild structural steel S235 under laser cutting process is investigated.

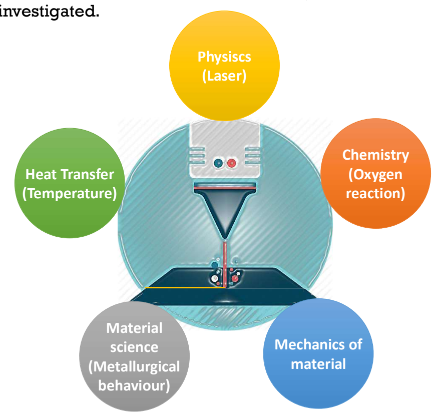

Fig. 1

Material and method

During the cutting process, a transient heat flux which is a combination of laser beam and oxygen-iron reaction, causes a dramatic change in material temperature. Based on temperature variation through the cut specimen, metallurgical and mechanical properties of the base material change [2]. To observe the phenomena, proper experiments including laser cutting, temperature monitoring, microconstituents photography of the material and, measuring residual stresses by X-ray diffraction (XRD) method are performed. In order to avoid costly and time-consuming experiments, a thermomechanical numerical simulation based on Finite Element method (FEM) is developed using ABAQUS software to predict residual stresses through the cut specimen, considering induced strains caused by micro expansions of the heated material. In order to precisely model a thermomechanical process of steel, considering microstructural behavior of the material such as phase transformations during heating and cooling is very important. As it is seen in Fig .2 different phenomena such as thermal, metallurgical and mechanical processes are dependent on each other that should be taken into account.

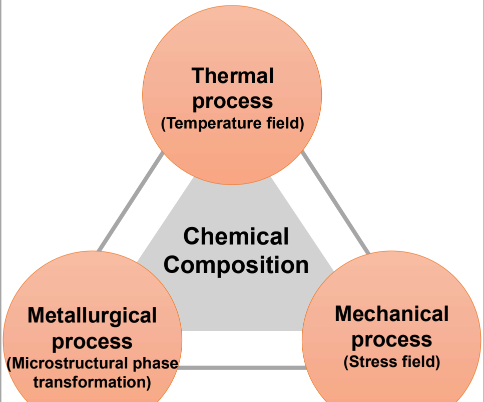

Fig. 2

Experimental setup

In order to have information on the actual LC process and on the effects on the material, thermographic monitoring of the specimen surfaces during the cutting process and chemical analysis on the HAZ were carried out. In this regard a set of two Optris IR cameras including Xi 400 with temperature range of 150 – 900 C and PI 800 M with temperature range of 575 – 1900 C were utilized (Fig.3).
Another way, which is reasonably cost effective, to measure the temperature is utilizing thermocouples in desired positions. In this regard, a datalogger RSPro1384 (4channels) was used as measuring instrument with thermocouples type K (RS code: 621-2170) (Fig. 6).
In order to see the kerf size and calibrate the model, also to see the heat affected zone(HAZ) and microconstituent changes, a light microscope was used as seen in Fig.4.
The position of the specimen and the measuring point with thermocouple is shown in Fig. 5.
Temperature distribution recorded by IR cameras are illustrated in Fid. 7 and Fig. 8.
These data were used to as a reference point for calibrating the process and also a for the thermocouple.
The cutting parameters are also reported in the table below.

Test number	Power (W)	Speed (mm/s)	Dimension	Parameter type	focal point (mm)	Gas pressure (bar)	Stand off (mm)	Measurement surface
1	3000	1100	35*35*12 mm	Standard	1.7	0.75	1.5	Top surface

Fig. 3

Fig. 4

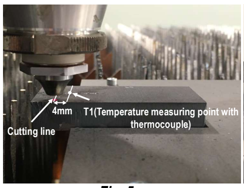

Fig. 5

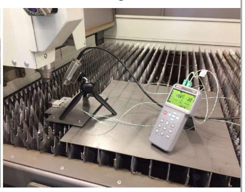

Fig. 6

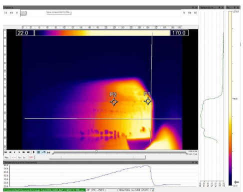

Fig. 7

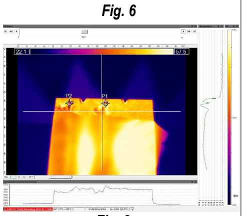

Fig. 8

Computer simulation

Laser cutting process is implemented in a model in Abaqus software and through some subroutines which are developed using Fortran language. The subroutines are used for applying the thermal load into the simulation process and modeling the material behaviour.
The following calibrated formula of volumetric heat flux, which is a combination of gaussian laser beam and exothermic reaction of oxygen with iron, for numerical modelling based on actual measurements on laser cutting process with oxygen assist gas was used.

$$Q = \frac{(c_1(w_i+\frac{w_u-w_i}{h}z)+c_2)q'h}{\pi[w_i h+(w_u-w_r)z]^2}\exp\left[-K_2\frac{(x^2+y^2)h^2}{[w_i h+(w_u-w_i)z]^2}\right]$$

Result and discussion

Fig. 9, 10, and 11 depict the fitted model on corresponding experiments. As it can be observed from these figures, the shape of the kerf is matched very well. In the following, Figs 12 and 13 illustrate the temperature history in the measuring point during the time and transverse residual stress along the depth of the specimen.
All the experimental and numercal results for a certain set of parameters are shown in these two graphs.

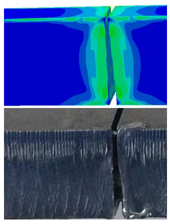

Fig. 9

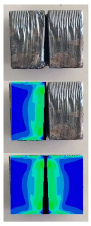

Fig. 10

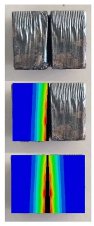

Fig. 11

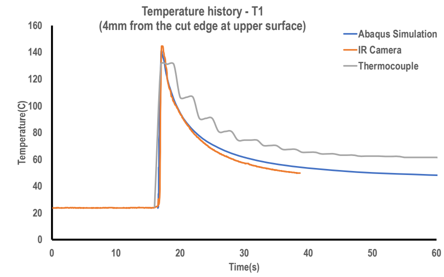

Fig. 12

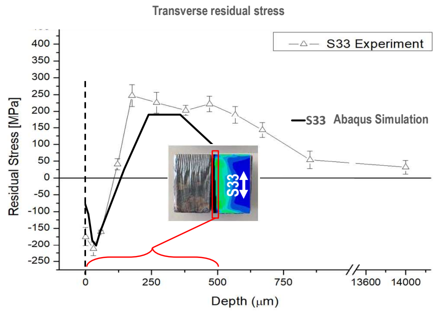

Fig. 13

Conclusion

The results showed a good agreement between numerical model and experiments that represent compressive stress at the cut edge and stress variation in the HAZ which are because of martensitic phase transformation of Austenite and plastic deformation of heated material. Further investigations will be using machine learning to predict the behavior of the material and optimization of the process.

Acknowledgment

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UNIVERSITÀ DI TRENTO

FONDAZIONE BRUNO KESSLER

Doctorate Program in Industrial Innovation

BLM GROUP

Contact

Majid Shamlooei

Majid.Shamlooei@unitn.it