Expert Laser System - Practical application of the power factor model for keyhole laser welding

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Summary

Laser processing is currently highly dependent on user knowledge and experience to choose correct parameters to obtain a reliable and high quality joints. Alternatively for every new application or different laser system a new process development is required. This is the reason that laser processing is often called as 'black art' which limits the exploitation of laser based production process in industry. The development of the Expert Laser System (ELS) for keyhole CW laser welding greatly simplifies the selection of laser welding parameters. The ELS contains the power factor model, which enables achievement of a particular penetration depth with variable beam diameter, and a Graphical User Interface (GUI) for easier utilization of the model. The user only needs to set the quality requirements for the laser process and the joint (i.e. productivity, fit-up tolerance, penetration depth etc.) and the ELS specifies the optimum welding parameters from these requirements. This means that the process parameters are selected based on quality requirements, rather than on system requirements. Using the power factor and on-board database the ELS is capable of adjusting the welding parameters according to the current status of the optical system. The user requirements can be easily transferred from one laser system to any other with minimal process development. Furthermore for a new application the user just inputs the new requirements and the ELS will update the welding process without extensive process development To prove the viability of the ELS, the power factor concept was extended to a wider range of group of metals such as mild steel, aluminium and titanium for different material thicknesses, beam diameters and joint configurations. The ELS can potentially be integrated into the control system of a commercial laser system or into an online monitoring system to guarantee consistent welds.

What is the power factor model?

For a non-expert user or in the case of using a new optical set-up it is often difficult to select the right processing parameters to achieve a required weld depth and quality. The challenge is exacerbated in the cases where the optical set-up changes over time due to degradation of optics or with multiple systems working simultaneously. The traditional parametric approach to determine the correct welding parameters is costly, time consuming and wasteful and it is unique to a particular system. The power factor model was developed for CW keyhole laser welding to overcome all these issues. The power factor is a phenomenological model which enables achievement of a particular weld profile (depth and width) independent of the laser beam diameter [1].

The investigation of laser material interaction showed that the same weld depth and width can be produced with different combinations of laser power and travel speed. In addition, for a constant combination of laser power and travel speed, the weld depth will vary if the beam diameter varies. This means that there are a multitude of parameters to consider when developing a laser process

Unlike the system parameters (laser power (P) and travel speed (TS)), which are specific to a particular system, the fundamental laser material interaction parameters (power density (q_P), interaction time (t_i) and specific point energy (E_{sp}), equations 1 to 3) characterise the response of the material to the laser energy and because they take into account the beam diameter (D_{beam}) the process is specified more uniquely. The depth of penetration in keyhole regime is controlled by the power density and specific point energy and the interaction time controls the weld width. It was found that under certain conditions this can be simplified and the weld depth is proportional to the interaction time and ratio of the laser power to the beam diameter (equation 4). It was shown that when the beam diameter was varied at constant interaction time and power factor (PF) the weld depth remained constant.

- Power density, MWm^{-2} $$q_P = \frac{P}{A_{beam}} \quad (1)$$
- Interaction time, s $$t_i = \frac{D_{beam}}{TS} \quad (2)$$
- Specific point energy, kJ $$E_{sp} = PD \times t_i \times A_{beam} \quad (3)$$
- Power factor, MWm^{-1} $$PF = \frac{P}{D_{beam}} \quad (4)$$

The empirical data for the power factor model are shown in Figure 1, which is based on several welding experiments. The graph shows the correlation between the power factor, interaction time and the penetration depth (PD). The model combines three system parameters into two and it is shown that there are infinite number of combinations of power factor and interaction time for any weld depth, but every combination results in different weld profile and quality, i.e longer interaction time usually results in wider welds and smoother beads.

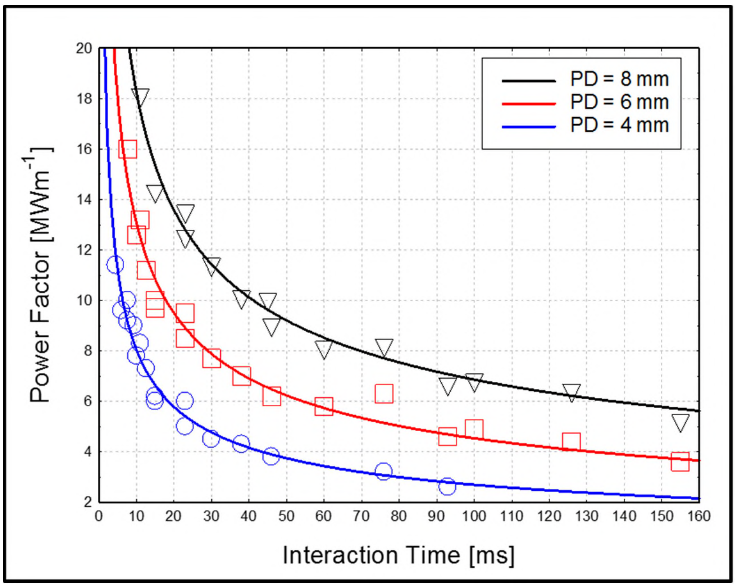

Figure 1: Power factor model for CW keyhole laser welding [2].

To prove the robustness of the power factor model several tests were carried out under different welding conditions.

- Application of the PF model to a wide range of beam diameters

One of the benefits of using the power factor model is the transferability of the results between laser systems with different optical set-ups. If a particular combination of power factor and interaction time is used to produce a weld using a Laser A then the same weld should be possible to achieve on a Laser B, just by calculating the required power and travel speed to achieve the same power factor and interaction time for a given beam diameter using equations 2 and 4.

Several experiments were carried out to prove that the weld depth was independent of the laser beam diameter when the power factor and interaction time were both constant. In these experiments the power and travel speed were continuously adjusted as according to the beam diameter in order to keep the power factor and interaction time constant. Figure 2 shows that the weld depth remains constant when the beam diameter changes. As the power factor is constant (6.6 MW.m^{-1}), the weld depth increases only when the interaction time increases.

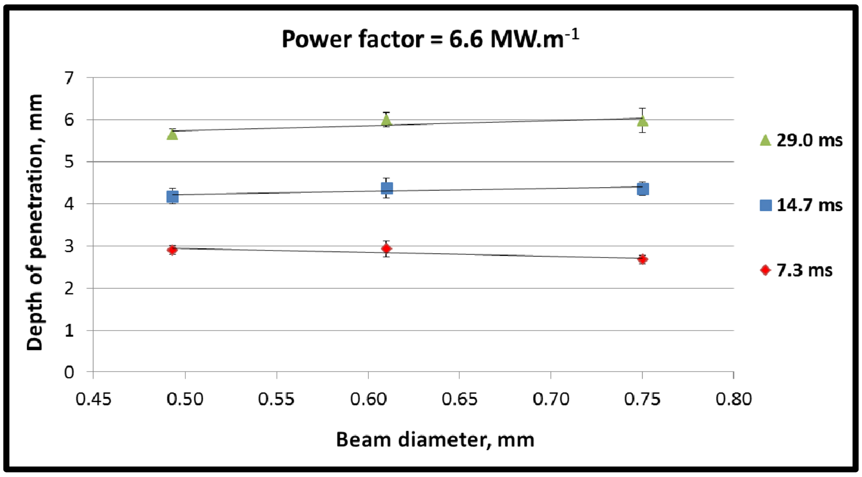

Figure 2: Effect of the laser beam diameter on the weld depth of penetration for constant power factor and different levels of interaction time.

The power factor model was tested and validated for a wide range of beam diameters between 180-780 µm. Within this range the weld depth remained constant.

- Application of the PF model to different metals

The power factor model was tested for different group of metals. Keyhole welds were produced in mild steel, aluminium and titanium and compared (see Figure 3). Even though the physical properties of the three metals are very different the three curves follow similar trend and there is a small offset between the materials.

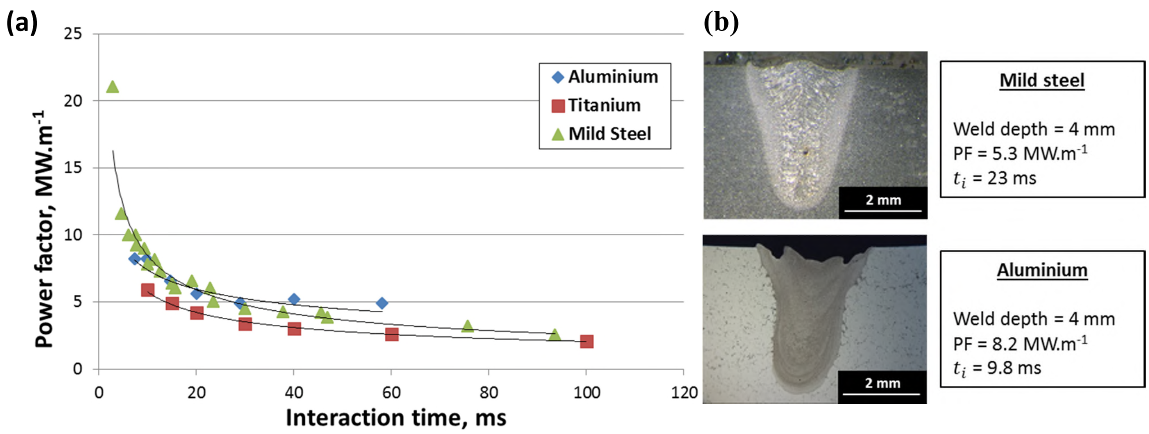

Figure 3: (a) Power factor model applied to different types of metal: Mild steel, aluminium and titanium. (b) Cross-sections of the 4 mm deep welds in mild steel and aluminium.

This is an important finding because it shows that a generic model can be used to determine the welding parameters for a particular material thickness. Figure 3b shows the cross-sections of the welds produced in mild steel and aluminium substrate and shows high similarity.

- Application of the PF model to different joint configurations

The power factor model was developed for butt welding however, the majority of the welding applications require joining in other joint configurations, such as lap-joint or partially penetrated welds. In order to assess whether the power factor model could be used in other joint configurations, the same welding parameters were compared for bead-on-plate, butt and in lap-joint configuration. The material thickness in both joint configurations was equivalent, i.e. 4 mm thick steel used in bead on plate configuration and two steel sheets, 2 mm thick each in lap joint configuration. In Figure 4 an example for a 3 mm weld depth is shown. The cross-sections of the welds produced in bead-on-plate and lap-joint configurations are very similar.

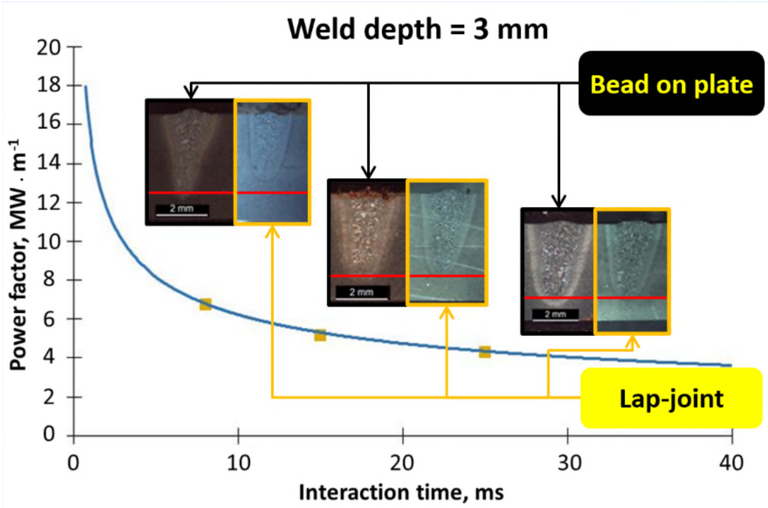

Figure 4: Power factor model applied to different joint configurations: Bead on plate and lap-joint.

The results suggest that within the experimental range the thermal distribution across the material in both joint configurations is similar despite of the interface between the sheets in the lap-joint configuration.

What is the Expert Laser System?

The Expert Laser System (ELS) is a graphical user interface with the power factor model integrated designed to help the laser user to choose the welding parameters for a required application (Figure 5). The laser user must follow the following steps:

1. Select material: The graphical user interface contains a selection of group of materials that the laser user can choose, including mild steel, aluminium and titanium.
2. Specify weld depth: The weld depth is usually the most important feature of the weld. Depending on the material thickness, deeper or shallower welds could be required. Moreover, depending on the application a partial or fully penetrating weld can be required.
3. Specify laser beam diameter: Different laser systems have different optical configurations and therefore, the laser beam diameter varies.
4. Specify the operating limit of the system (laser power, processing speed) or weld quality (interaction time): Depending on the processing restrictions (maximum output laser power or maximum speed of the motion system) the user will select laser power or travel speed and insert a corresponding value. Alternatively the user can fix the interaction time having in mind that a longer interaction time produces welds with higher quality and better fit-up tolerance whereas processing with shorter interaction time offers higher productivity and narrower welds due to higher processing speed.

5. Press calculate: The ELS will calculate the processing speed (if the user chose laser power) and laser power (if the user chose processing speed or interaction time) needed to achieve a particular weld beam for a particular beam diameter.
6. Observe the results: The ELS will display both the system parameters and the fundamental parameters.

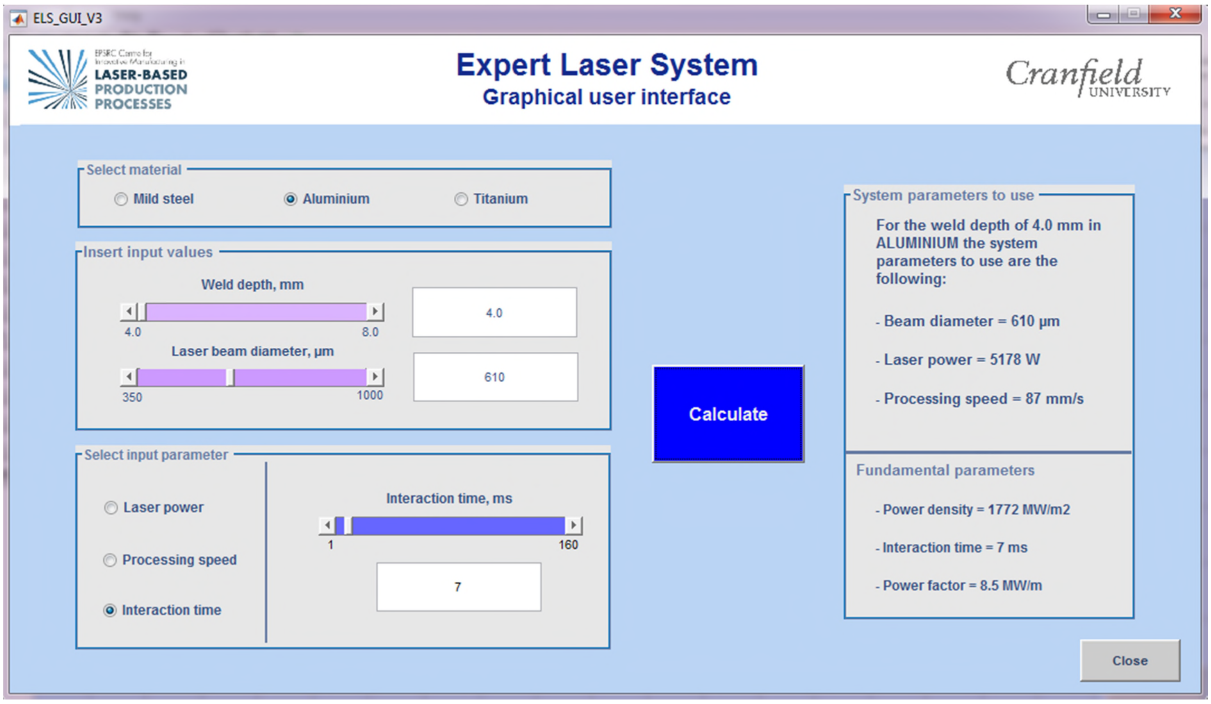

Figure 5: Expert Laser System.

What are the main benefits of the Expert Laser System?

- Determine the laser parameters based on the user requirements (productivity, fit-up tolerance, penetration depth etc.);
- Transferability of the results between laser systems with different laser beam diameters;
- Can be applied to multiple metals;
- Can be applied to bead on plate and lap joint configurations;
- Can potentially be integrated into the laser control system or into process monitoring.

References

[1] W. J. Suder and S. Williams, "Power factor model for selection of welding parameters in CW laser welding," *Opt. Laser Technol.*, vol. 56, pp. 223–229, Mar. 2014.

[2] W. Suder, "Study of fundamental parameters in hybrid laser welding," Cranfield University, 2012.

Acknowledgements

I would like to acknowledge those who contributed to this work: Dr. Wojciech Suder, Prof. Stewart Williams, Dr. Supriyo Ganguly, Mr. Julio Coroado.

2017-09-30

Expert Laser System: Practical application for keyhole welding

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