THICK STRIP CUTTING AND WELDING WITH HIGH POWER SOLID-STATE LASER TECHNOLOGY BREAKTHROUGH*

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Abstract
Steel strip manufacturing ever reinvents proposing new grades, requiring to tackle technical limitations of production systems. Primetals Technologies breaks through strip welding by expanding the welder LW21L "Asolid" technology used on low gauges for high-end market such as automotive CAL/CGL. Addressing the usual drawbacks in maintenance, operation and safety of current welding system based on mechanical cutting and CO2 laser welding, the newly developped LW21H "Asolid" technology processes thicker strips up to 7 mm with solid-state laser cutting and welding. This new welder is brought to reality through a scale 1:1 pilot developed, manufactured and tested in Primetals Technologies workshop.
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1 INTRODUCTION

Flat steel production reinvents itself everyday by constantly proposing new grades and dimensions, which requires to tackle the technical limitations of production systems. Primetals Technologies contributes to the evolution in strip welding solutions in submitting a disruptive development out of the solid-state laser technology currently used on low and medium gauges for high-end market such as automotive CAL/CGL since 2011. Addressing the usual drawbacks in maintenance, operation and safety of current welding system based on mechanical cutting and CO_2 laser welding, the newly developed laser welder LW21H processes thicker strips up to 7 mm with solid-state laser cutting and welding. This new welder is brought to reality through a scale 1:1 pilot developed, manufactured and tested in Primetals Technologies workshop.

2 DEVELOPMENT

2.1 Mechanical description

The new Heavy Laser LW21H is able to weld a wide range of strip thickness from 0.7 mm (0.027”) to 7 mm (0.276”), and width from 600 mm (23”) to 1880 mm (84”) within a short cycle time and with a wide range of materials.

Figure 1. Laser welder at Primetals Technologies workshop

As experienced by users of laser welding machines, the alignment (and reproducibility of alignment) of the machine and laser beam path is the key of maintaining the optimum welding performance.
Primetals Technologies design undertakes those problems by using optical fiber for the transmission of the laser power and by separating respectively the mechanical functions of cutting system, welding system, and strip heads position control. In order to ensure the perfect matching of the cutting and welding path, the two process carriages are moving on the same mechanical sideways.

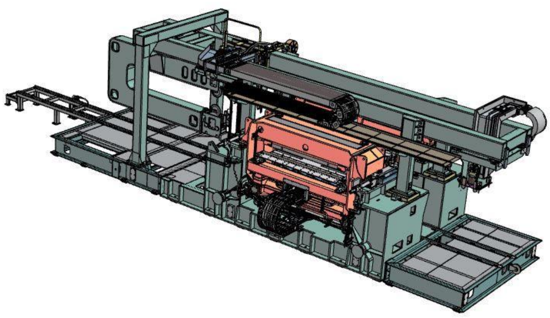

Figure 2. Laser welder overview

As a key function, the laser cutting has been carefully engineered to reach the cycle time performance of a machine equipped with a mechanical cut. The cutting carriage includes two cutting heads, one in entry and one in exit. They are installed at an accurate and fixed distance and are perfectly vertical to the strip surface. Both heads are therefore moving on the same linear guiding way to compensate any defects along the cutting stroke (See figure 3).

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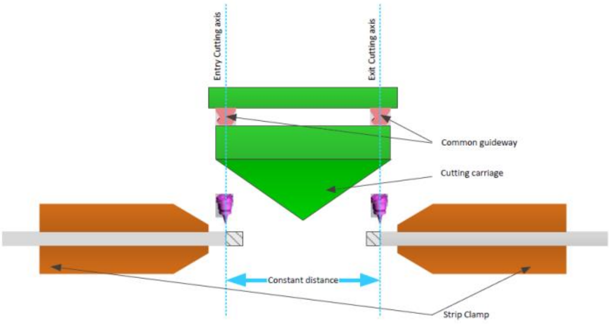

Figure 3. Constant cutting distance

Both strip tail and head edges are firmly clamped and positioned to a referenced mechanical position before the cut to reach a high gap accuracy, which is a critical point for laser butt welding processes.

Cutting is done by the two dedicated laser heads mounted on vertical slide ways and actuated by electrical servomotors.
A high nitrogen pressure gas flow (pressure controlled) is used to ensure a laminar flow at high speed. This flow guarantees a good evacuation of the melted metal and gives proper edge quality and shape for welding. The cutting heads are also equipped with a protection window fast and easy to change to protect the focusing lens. The strip is perfectly maintained on each clamp by independent sustain table so as to avoid burr defects.

2.2 High performance laser cutting head

The disruptive move from mechanical shear cutting to laser cutting is driven by the need to improve the cross-section shapes resulting from cutting. Mechanical cut surface patterns generally show two areas, respectively one of shear fracture and one of ductile fracture, and as shown below, a cross-sectional shape with larger gap for butting. The laser for welding goes through the gap, and it degrades the welding quality. By opposition, the cross-sectional shape resulting from laser cutting has perpendicular shape which is appropriate to laser welding.

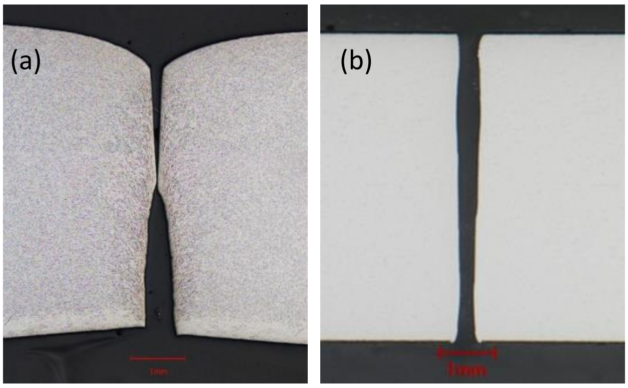

Figure 4. Cross-sectional cutting shape by (a) mechanical shear, (b) laser cutting

When considering the disruptive move from mechanical shear cutting to laser cutting, the increased cutting time has always been seen as the major roadblock due to its detrimental effect on overall entry cycle time. In the case of laser cutting using nitrogen gas, the cutting speed primarily depends upon the laser power; in this regards, laser cutting heads available on the market were only able to be used up to 8kW, leading to an insufficient cutting speed (at higher gauges) to be in position to compete with the mechanical cutting solution. Primetals Technologies therefore decided to develop a high power laser processing technology in its Hiroshima facilities, precisely adapted to the targeted production and expected performance.

Figure 5. New high performance cutting head

The new cutting head was designed to be used at least up to 12kW laser power and for achieving both high speed stable cutting and optimum cutting quality. A complete new internal optical system was developed for that purpose, specifically designed to be able to be use up to 20kW laser power, and with a beam shape showing bigger Rayleigh length than optical systems usually available on the market.

Figure 6 below highlights the process robustness of Primetals Technologies optical system compared to other optical system available on the market. The comparison is made at a selected power (>10 kW) and focus position defined to process 6mm thickness strip. The maximum cutting speed can be reached in both cases, however, the new optical system can cut faster in secured conditions, by enabling a 2-times wider range of focus position.

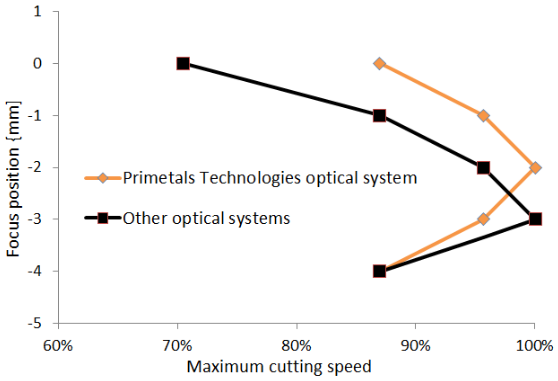

Figure 6. Relation of focus position and maximum cutting speed - comparison for different optical systems

Figure 7 shows the cross-sectional cutting shapes at some various focus positions. The new Primetals Technologies optical system ensure better perpendicular shapes compared to conventional type optical systems even if the focus position shifts.

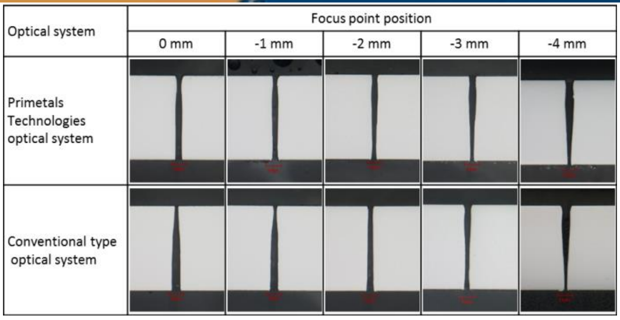

Figure 7. Cross-sectional laser cutting shapes on some focus positions

2.3 Optimized laser cutting and welding processes

Laser cutting is a technology that is getting more and more popular for industrial manufacturing applications and especially in the steel process industry to cut work piece. Laser cutting works by directing the output of the high-power laser through optics. The focused laser beam is directed at the material, which then melts and is blown away by a jet of high-pressure gas leaving an edge with a high-quality surface finish (fig 8).

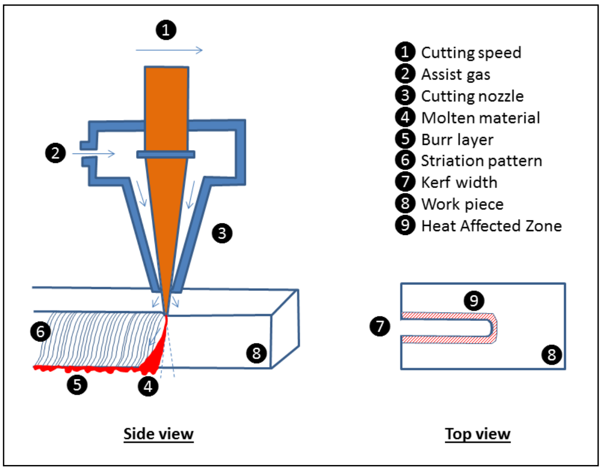

Figure 8. Laser cutting process

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Laser cutting is a complex process in which no fewer than 16 parameters participate with varying degrees of interaction:

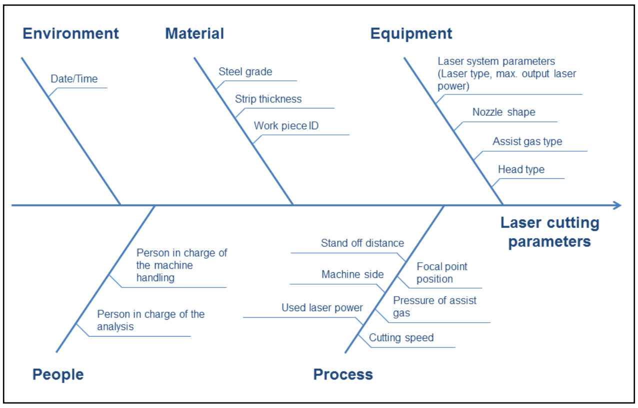

Figure 9. Ishikawa diagram highlighting the main laser cutting parameters

To a first approximation, the following 6 parameters have been considered to understand and model the laser cutting process: the steel grade, the strip thickness, the cutting speed, the focal point position, the assist-gas pressure and the nozzle type. Although the nature of the assist-gas and the used laser power make them as major parameters, those have been fixed for efficiency purpose. The assist-gas is nitrogen and the used laser power has been set to 12kW so as to transmit the maximum energy to melt the material and to cut at maximum traveling speed.

Taking account of the previously defined principal parameters, the goal of the analyses that have been carried-out was to examine the behavior of two nozzle types (orifice diameter and shape) to blow the assist-gas and to determine for a given laser and material configuration a stable operating range in terms of nozzle type, focal point position, nitrogen pressure and cutting speed. Ideally, the proposed operating window should match all the process constraints, namely a high cutting speed to ensure a minimum cycle time, a low pressure to minimize the gas consumption and a high-quality edge cut to ensure a future high welding resistance. To achieve that goal, the Design of Experiments (DoE) methodology was used. The objective was, with a reduced number of trials, to establish a polynomial modeling of the cutting quality with respect to given parameters. The method enables to model parameters linear (X_i) and quadratic (X_i^2) effects as well as 1-order interactions between each parameter ($X_1.X_2$, $X_1.X_3$, etc.). For all the continuous factors, an adequate range of variations was preliminary determined (for instance, nitrogen pressure within the range [2 .. 20] bars). Moreover, in order to test the process repeatability, the point at the center of the working domain was duplicated 5 times.

For each trial, the cutting quality was evaluated. Such an evaluation is not easy and was finally based on several experimental assessments: an overall kerf wall quality estimation using a Müdge criterion scoring, a measurement of the tilt angle (transition of the molten material from laminar flow to turbulent one), a measurement of the burrs layer thickness and an estimation of the required laser power based on the measurement of the kerf width [1]. All the runs with a complete cut have been shot using a micro-camera. From the visual point of view (fig 10), results show an excellent correlation with the effect described by various authors [1, 2]

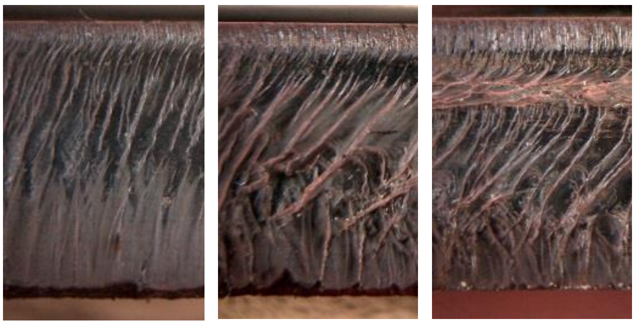

Figure 10. Influence of the assist-gas pressure on the kerf wall surface quality

The whole analysis and modeling of the various physical phenomena was carried out using predictive and statistical analysis software. Once modeled with accuracy, the models were put together to determine optimal set points for each laser and material configuration. These set points have been determined in such a way that a complete cut is possible, an acceptable cutting quality is produced and the welding cycle time is minimized.

From the welding point of view, the parameters to take into account are even more numerous [3] and the results are highly steel grade-dependent (fig 11):

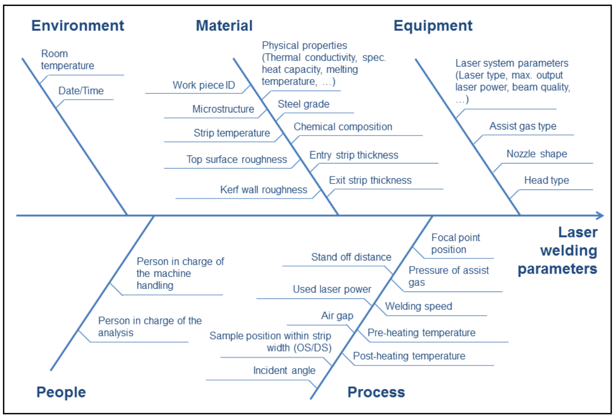

Figure 11. Ishikawa diagram with the main laser welding parameters

To a first approximation, the following 6 parameters have been considered to understand and model the laser welding process: the steel grade, the entry strip thickness, the exit strip thickness, the welding speed, the focal point position, the used laser power. The main difficulty comes from the fact that several flaws can appear during welding, the main ones being the lack of penetration, a deep groove at the top of the weld bead, cracks and porosities inside the weld and, to a lesser extent, the humping effect [4]. Each of these flaws can be plotted into a power/speed chart and define the limits of the so-called weldability lobe (white area on fig 12).

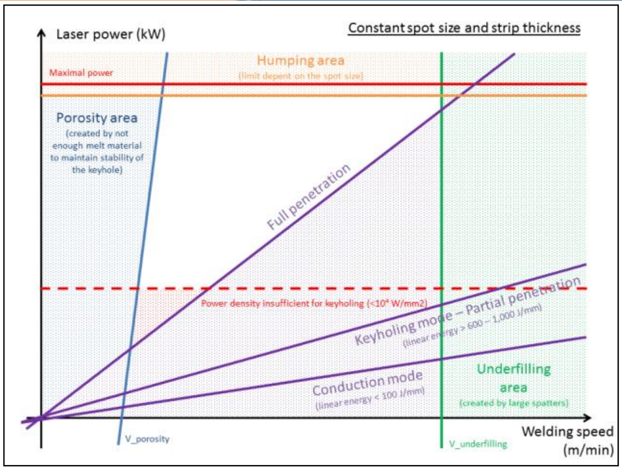

Figure 12. Main flaws location in a power/welding speed chart

The analysis methodology is the same as the one used for the laser cutting. For each trial, the welding quality has been evaluated not only visually but also using an instrumented ball test so as to estimate the weld resistance (also online welding quality evaluation). Optimal welding set points are then determined in such a way that the laser power and welding speed belong to the weldability lobe and the weld resistance is acceptable.

3 CONCLUSION

The extension of proven Primetals Technologies thin strip laser cutting and welding concept to thicker strips has been reached by Primetals Technologies thanks to adaptation of high power solid state laser. Through the development of a dedicated high performance laser cutting head, the comprehensive analysis and optimization of cutting and welding processes, and ultimately the construction of a scale1:1 pilot machine, qualification tests have been carried out to confirm the capability of such disruptive solution. The major breakthrough on high speed laser cutting leads not only to optimum quantity levels, but also to higher robustness with significantly less sensitivity to incoming material variations and clearly pave the ground for alternatives to mechanical-cut based solutions.

REFERENCES

1 Catherine Wandera, Veli Kujanpää, Antti Salminen, Laser power requirement for cuting of thick-section steel and effects of processing parameters on mild steel cut quality, Laapeenranta University of Technology, Finland, 2011

2 Majid Hashemzadeh, Investigations into fibre laser cutting, University of Nottingham, 2014

3 C. A. Walsh, Laser welding – Literature Review, University of Cambridge, England, 2002

4 Mikhail Sokolov, Antti Salminen, Improving laser beam welding efficiency, Lappeenranta University of Technology, Finland, Engineering, 2014, 6, p 559-571