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Benchmarking Productivity and Cost-effectiveness of Multi-kW Laser Cutting across Industrial Cutting Technologies

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Abstract

Laser cutting is widely employed in sheet metal processing due to its high productivity and flexibility, enabling tailored industrial solutions. However, its efficiency decreases when processing thick-section metal sheets, where alternative cutting technologies are often preferred. The reduction in cost-per-kilowatt and laser source prices, driven in particular by Asian manufacturers, has contributed to the development of ultra-high power laser cutting systems, enhancing the technical and economic feasibility of laser technology relative to established cutting methods for high thickness applications. This study presents a comparative analysis of current industrial technologies for processing thick-section metals. Industrial datasets were collected to evaluate productivity for laser, plasma arc, oxyfuel, and abrasive waterjet cutting. Findings indicate that plasma arc cutting maintains high productivity across a wide thickness range. Laser systems potentially achieve comparable speeds at power levels above 30 kW, while economic competitiveness primarily depends on reductions in the laser machine investment cost.

Keywords: Laser cutting; Thick-sheet metal processing; Productivity; Cost-analysis

1. Introduction

Laser cutting is a manufacturing technology widely employed in metal processing, taking advantage of its high precision, non-contact nature, and capability to efficiently work on a wide range of materials [1]. Nevertheless, cutting limitations arise when processing thick plates, which is commonly required in heavy-duty applications such as construction, shipbuilding, and dismantling operations [2], [3]. In this field, alternative technologies, including plasma arc, oxyfuel, and abrasive waterjet cutting, are adopted, each offering distinct advantages tailored to industrial requirements [4], [5]. Among these, plasma arc is recognised for its high productivity and cost-effectiveness, although it generally provides lower cutting quality [5]. Technological advancements expanded the capabilities of laser cutting systems for the processing of thick materials through higher power intensities [6]. Developments focus on overcoming thermal management limitations, which represent a key challenge in scaling laser output power, particularly within the laser source and the cutting head [7]. Over the past decade, the reduction in cost-per-kilowatt and laser source prices, especially among Asian manufacturers, has driven the diffusion of high-quality multi-kilowatt laser sources, supporting the transition towards ultra-high power (UHP) laser cutting systems [8]. These advancements have made the extent of the performance gap between conventional thick-plate cutting methods and laser technology increasingly uncertain; therefore, an updated comparative assessment of their respective capabilities and application domains is required. The present study proposes a comparative analysis of

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cutting technologies for sheet metal processing, including plasma arc, oxyfuel, abrasive waterjet, and laser cutting. Efficiency is established through collection and analysis of data from public databases, investigating the relationship between power, cutting speed, and material thickness. Additionally, a structured cost breakdown analysis is done to assess the cost-effectiveness of high-power laser and plasma arc cutting systems. A sensitivity analysis is further conducted to evaluate the influence of the machine investment on the overall process cost. The findings aim to support decision-making in selecting the appropriate cutting technologies by highlighting recent technological developments and possible future perspectives.

2. Materials and Methods

2.1. Data collection and statistical model fitting

The data collection process was designed to gather accurate information on cutting speed, material thickness, and energy consumption for abrasive waterjet, oxyfuel, laser, and plasma arc cutting technologies. To ensure a uniform comparison, all collected data refer to carbon steel processing operations, and only thicknesses equal to or greater than 10 mm were considered. Data for waterjet and oxyfuel cutting were retrieved from publicly available datasets. Abrasive waterjet data correspond to process parameters associated with the KMT Classic 3800 bar pump [9], while oxyfuel data refer to cutting conditions using acetylene as the fuel gas (GCE Arc Nozzles [10]). Plasma arc cutting data were provided by Hypertherm (Hypertherm, New Hampshire, USA) for 170 A, 300 A, and 460 A current rates. Reactive fusion laser cutting data were collected through a survey of multiple laser systems manufacturers to ensure representativeness of current industrial capabilities. Due to the proprietary nature of the data, the specific sources are not disclosed in this work. Based on the availability of multiple data points, a regression model was developed using the collected datasets to capture the relationship between cutting speed (v), power (P), and material thickness (t), as following Equation (1):

$$v\ [mm/min] = f(P\ [kW], t\ [mm]) \quad (1)$$

A p-order multiple polynomial regression model (Equation (2)) was adopted to describe the non-linear relationship between the input factors and the response variable.

$$y = \beta_0 + \sum\nolimits_i \beta_i x_i + \sum\nolimits_{i \le j} \beta_{i,j} x_i x_j + \cdots + \epsilon \quad (2)$$

Statistical software was used to do the regression analysis, allowing iterative model refinement based on the significance of individual terms, with removal level α fixed to 0.05.

2.2. Cost modelling of cutting processes

The model was formulated to estimate the average cost per meter of cut for a specific material thickness, based on annual operating data and under the assumption of unlimited material availability. For the comparison of cutting technologies, the total yearly operating cost (C_{tot}) was divided into fixed (C_{fixed}) and variable ($C_{variable}$) components. In the proposed formulation, the fixed cost component is represented by the initial investment cost of the cutting system (C_{system}), amortized over the expected operational lifespan (L_{sys}). Variable cost components, which depend on operational usage, are determined through the terms reported in Equation (3).

$$C_{variable} = C_L + C_E + C_G + C_M \quad (3)$$

C_L represents the annual operator cost, calculated from the hourly unit labour cost (C_{labour}) and the total available working time (T_{tot}). The energy cost (C_E) accounts for the electricity price ($C_{electricity}$), the power consumption of the cutting machine (P_{mac}), the chiller ($P_{chiller}$), and auxiliary devices (P_{aux}), as well as the overall electrical efficiency (η). The annual gas cost (C_G) is calculated based on the assist gas price. Both C_E and C_G depend on the effective processing time. The maintenance cost (C_M) represents the yearly expenses associated with system servicing. The average cost per meter of cut for a specific material thickness ($C_{m,t}$) (Equation (4)) is calculated as the ratio between the yearly total cost of operating the system (C_{tot}) and the total annual cutting length. The latter was estimated by considering the number of plates of thickness t processed per year ($N_{plates,t}$), and the cut length associated with a single processed plate, under the assumption that a constant nesting geometry is considered throughout the year.

$$C_{m,t} = \frac{C_{tot}}{N_{plates,t} \cdot L_{cut,plate}} \quad (4)$$

The yearly number of processable plates for a given thickness is estimated in the proposed model by considering the average cut length of a representative nesting geometry on a typical 4 m x 2 m metal sheet ($L_{cut,plate}$), the effective available working hours accounting for the system utilization rate (U), and the cutting speed achievable for that specific thickness. In the present research, the data used to develop the cost model were sourced from an industrial end-user of cutting systems (Sice Previt, Milan, Italy) and from the plasma cutting technology provider (Hypertherm, New Hampshire, USA). The values are reported in Table 1. Furthermore, a sensitivity analysis is conducted to explore how variations in cost drivers impact the overall cost-effectiveness.

Table 1. Data provided and assumptions made for cost estimation

Parameter	Plasma arc	Laser
Expected operational lifespan, L_{sys}, [years]	5	5
Total available time, T_{tot} [h/year]	4160	4160
System utilization rate, U [-]	50%	50%
Electrical efficiency, η [-]	95	30
Auxiliary devices power, P_{aux} [kW]	20	20
Labour cost, C_{labour} [€/h]	20	20
Electricity cost, $C_{electricity}$ [€/kWh]	0.15	0.15
Gas cost, C_{gas} [€/m^3]	/	1.75
Total cut length, $L_{cut,plate}$ [mm]	36000	36000

3. Results

3.1. Regression model on collected laser cutting data

The regression reported in Equation (5) was obtained as the best fit describing the collected data, and Fig. 1 displays the model trend for various power levels.

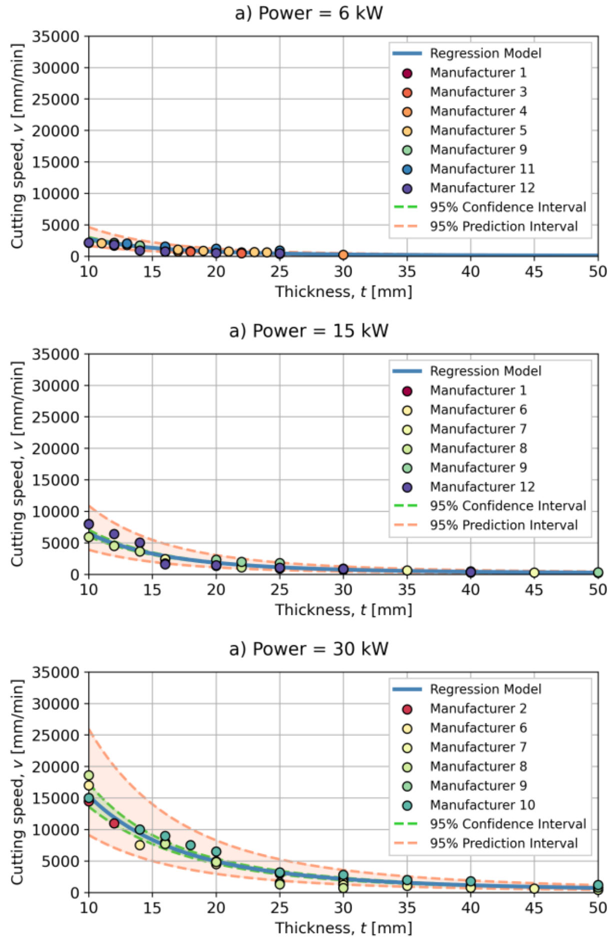

Fig. 1 Collected data (coloured points), and corresponding regression model with fitted curve for laser sources at different power corresponding to (a) 6 kW (b) 15 kW, and (c) 30 kW

A natural logarithmic transformation was applied, and the statistical analysis confirms the adequacy of the model, with consistent R^2 and R^2_{adj} values, a non-significant lack-of-fit test, and normally distributed residuals.

$$\ln(v) = 9.091 - 0.21t + 0.123P + 0.00294t^2 - 0.00219P^2 + 0.00161tP - 0.000013t^3 + 0.000012P^3 - 0.000023t^2P \quad (5)$$

3.2. Productivity comparison between advanced cutting processes

Fig. 2 shows the cutting speeds for carbon steel in logarithmic scale as a function of material thickness. Among the investigated technologies, abrasive waterjet cutting exhibits the lowest productivity. Oxyfuel cutting becomes competitive with laser cutting for thicknesses above approximately 20 mm, corresponding to the transition threshold for 6 kW laser systems. Its relative productivity further increases with thickness, surpassing 15 kW laser and 170 A plasma arc cutting strategies for thicknesses exceeding 40 mm. Within the 20-45 mm range, laser and plasma arc cutting performances depend on the selected power or current levels. For laser systems operating at lower power levels (6-12 kW), technological feasibility at higher thicknesses is not consistently guaranteed according to the collected datasheets, as highlighted by the dashed lines in Fig. 2. The adoption of high-power laser sources, such as 30 kW and 60 kW systems, extends process capability and productivity, reaching levels comparable to plasma arc cutting at current levels above 300 A.

3.3. Cost per meter

The cost per meter analysis was performed for laser and plasma arc cutting, focusing on the two solutions exhibiting the highest productivity in carbon steel processing. A 30 kW laser and a 300 A plasma arc cutting system were selected for the comparison. In this study, laser cutting systems are assumed to have a fixed annual maintenance cost, whereas plasma cutting maintenance costs are primarily related to consumable

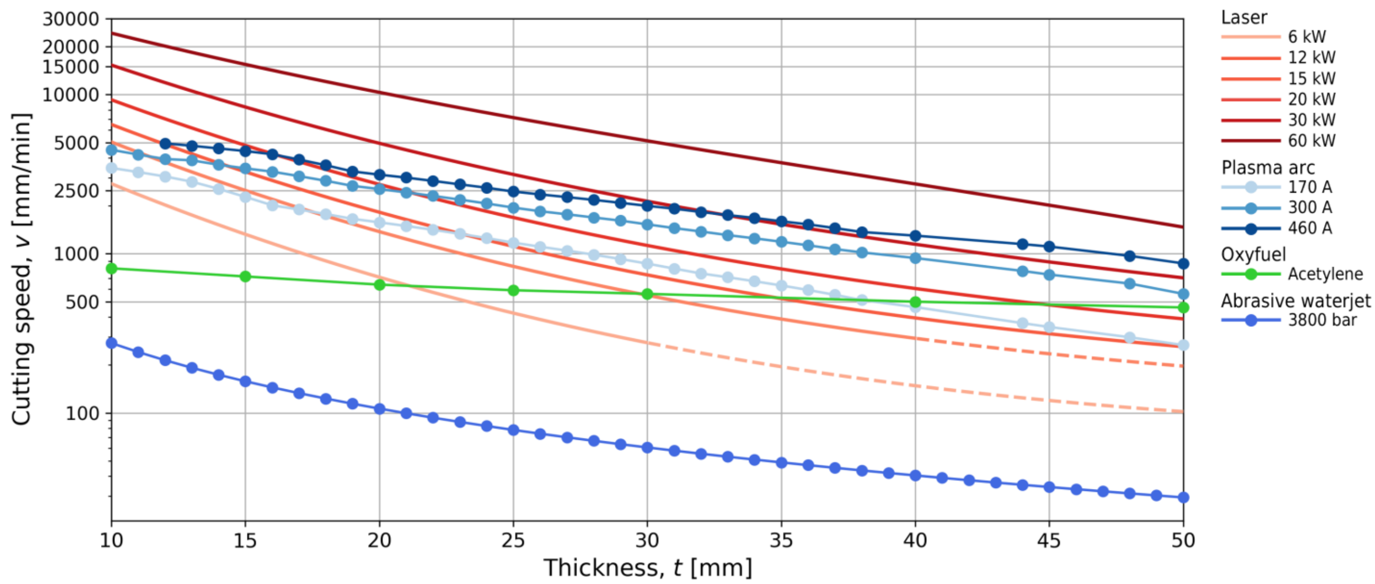

Fig. 2 Comparison of the cutting speed between laser, waterjet, oxyfuel, and plasma arc cutting across different carbon steel thicknesses. Solid lines for laser cutting are derived from the developed regression models, whereas dashed lines indicate thickness ranges where cutting is not technically feasible

components. Based on the sourced data, the initial investment cost was fixed at 850,000€ for the laser system and 155,000€ for the plasma arc solution. The analysis assumes that each machine processes a single material thickness, ensuring full utilization. Fig. 3 compares the cost per meter as a function of thickness, highlighting individual cost components. For both technologies costs increase with material thickness, mainly due to higher energy and labour requirements. Laser cutting shows a cost advantage up to 10-20 mm driven by higher cutting speeds.

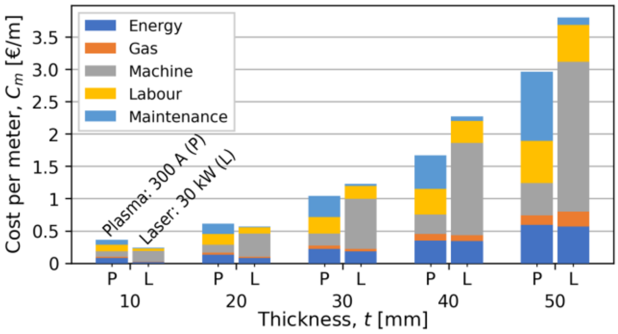

Fig. 3 Thickness-dependent comparison of cost per meter for carbon steel cutting between laser (L) and plasma arc (P) cutting systems

Beyond this range, plasma arc cutting becomes more economically favourable due to marginally higher productivity despite higher maintenance costs. A difference is also observed in the machine-related costs, where a large contribution is requested for the laser system. The impact of the investment cost for the laser machine is illustrated in Fig. 4. The results indicate that at 30 mm thickness, a reduction of about -25% in the laser system cost would enable cost parity with plasma arc cutting. For thicker materials, laser cutting becomes increasingly dependent on the machine cost, requiring reductions ranging from 25% to 50%.

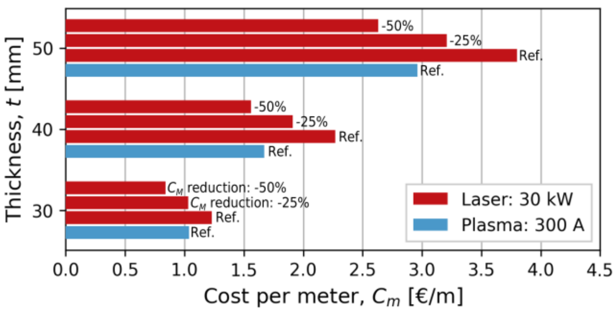

Fig. 4 Cost per meter sensitivity to laser machine investment cost for different material thickness

This work presents a comparative analysis of cutting technologies for carbon steel processing. Plasma arc, oxyfuel, abrasive waterjet, and laser cutting were investigated, with a focus on productivity and economic viability. The findings suggest that high-power laser cutting systems could extend the traditional advantages of laser processing to thick-section applications such as structural, construction, and dismantling operations. However, industrial feasibility remains influenced by the high initial investment cost of laser machines, which currently favours plasma arc cutting due to its high productivity at lower capital expenditure. In this regard, the ongoing reduction in cost-per-kilowatt and the subsequent increase in available laser power [8] could shift the economic break-even point between the two cutting technologies.

4. Conclusions

This study presented a comparative analysis of cutting technologies for carbon steel processing, including plasma arc, oxyfuel, abrasive waterjet and laser cutting. Findings aim to be representative of current industrial scenario, while also highlighting ongoing technological productivity and cost-effectiveness trends across different material thicknesses. The main results can be summarized as follows:

- A regression model built on industrial manufacturer data enables reliable cutting speed predictions across varying power levels and material thicknesses.
- Among the considered technologies, laser cutting represents a feasible solution up to 20-30 mm thickness in terms of productivity and cost perspectives. Beyond this range, plasma arc cutting demonstrates superior performance, whereas laser systems require higher power levels to maintain competitiveness.
- A reduction in laser system investment cost in the range of 25-50% has the potential to reduce the cost gap between the two technologies.
- A qualitative evaluation of cut quality was not included and represents a relevant topic for future research, potentially highlighting the advantages of laser-based technologies. From a general perspective, the latter comprise minimal heat-affected zone, tight tolerances and narrow kerf widths, resulting in high precision cuts. Additionally, the architecture of laser systems enables flexible and seamless integration into automated manufacturing environments, while the absence of process media ensures a clean solution free from handling and disposal operations.
- The long-term maintenance costs and the effects of high power levels on material behavior and machine integrity require further investigation. In particular, component degradation and overall system reliability should be addressed, as well as process stability during cutting operations. In this regard, the applicability of laser-based technologies may be limited by material surface conditions and reflectivity properties.

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