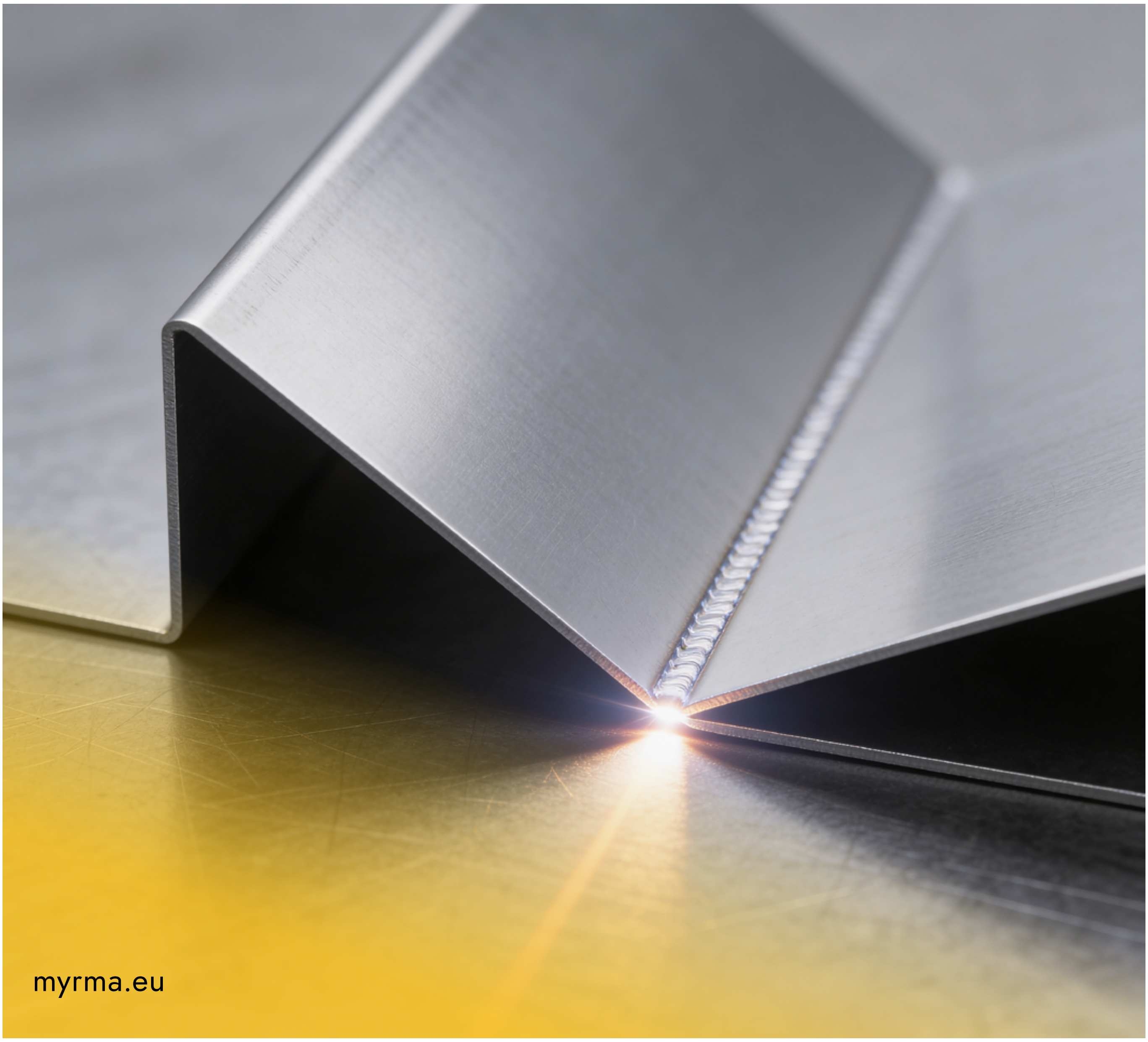
LASER WELDING OF ALUMINIUM

PROCESS STABILITY AND JOINT REPEATABILITY IN INDUSTRIAL PRODUCTION



Laser Welding of Aluminium

Aluminium has long been one of the key structural materials in industry - from automotive, through energy, to advanced enclosure systems and precision components. **Its low weight and good mechanical properties** make it the natural choice wherever the strength-to-weight ratio matters.

From the perspective of material joining technologies, aluminium remains a demanding material. In particular, **laser welding of aluminium places high demands on process stability and parameter control.** In industrial practice, the key question is not whether a weld can be made, but whether **the process can be maintained in a repeatable and predictable manner under production conditions.**

Material Properties and Process Behaviour

The specific characteristics of aluminium in laser welding stem directly from its physicochemical properties. From an engineering standpoint, three factors are most significant.

The first is **high thermal conductivity,** which causes rapid dissipation of energy from the beam interaction zone. As a result, maintaining a stable weld pool requires precise delivery of energy in a sufficiently concentrated form.

The second factor is the **natural aluminium oxide layer (Al_2O_3).** Its melting point significantly exceeds that of the base material, which disrupts wetting and can lead to process instability.

The third aspect is **susceptibility to metallurgical defects**, particularly gas porosity and hot cracking. Their occurrence is closely linked to process parameters and material preparation.

Process Stability as the Main Challenge

Unlike many conventional welding methods, **the laser process is characterised by a narrow range of stable parameters.** Small deviations can lead to significant quality changes.

In practice, the following are commonly observed:

- instability of the penetration mode (transitions between conduction and keyhole),
- variable penetration depth,
- local weld discontinuities

For this reason, the key issue is not a single parameter, but **defining and maintaining a process window in which the process remains stable.**

Critical Parameters and Energy Balance

The primary variables influencing the process are:

- laser power,
- welding speed,
- focal position,
- shielding gas conditions,
- material surface condition.

The relationship between power and speed can be described by the linear energy of the process:

$$E = \frac{P}{v}$$

In practice, this means that **both too low and too high linear energy** can lead to defects — lack of penetration or excessive weld pool instability, respectively.

The Role of Surface Preparation

One of the most frequently underestimated factors is material preparation before the process. Even optimally selected parameters will not ensure stability if the surface does not meet quality requirements.

Of critical importance are:

- removal of the oxide layer,
- elimination of organic contaminants,
- ensuring repeatable input conditions.

In production conditions, this means that **standardisation of the part preparation process is essential.**

Limitations and Implementation Risks

Laser welding of aluminium will not be the optimal solution in every application. Problems arise particularly when:

- the material shows high compositional variability,
- there is no control over surface preparation,
- the joint geometry does not favour stable process guidance,
- parameters are selected without prior validation.

In such cases, the risk of process instability and lack of repeatability increases significantly.

The Importance of Process Validation

From an industrial implementation perspective, process verification before production implementation is a critical step.

This includes:

- testing on actual materials,
- defining the process window,
- weld quality analysis,
- assessment of defect susceptibility,
- repeatability verification.

Indicative Laser Welding Parameters for Aluminium (Technological Ranges)

Material Thickness [mm]	Laser Power [kW]	Welding Speed [m/min]	Process Mode	Typical Application
0.5 – 1.0	0.5 – 1.5	3 – 10	conduction / shallow keyhole	thin-walled enclosures, electronics
1.0 – 2.0	1.0 – 2.5	2 – 6	transitional / keyhole	precision components, automotive
2.0 – 4.0	2.0 – 4.0	1 – 3	stable keyhole	load-bearing structures, profiles
4.0 – 6.0	3.0 – 6.0	0.5 – 2	deep keyhole	structural elements
6.0 – 8.0	5.0 – 8.0	0.3 – 1	deep keyhole / multi-pass	heavier components

This approach enables the transition from the experimental stage to a controlled production process.

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Laser Welding vs. Conventional Methods

Compared to methods such as TIG or MIG, laser welding of aluminium offers a number of significant advantages:

- higher process speed,
- limited heat-affected zone,
- reduced distortion,
- better repeatability in series production.

At the same time, this technology is more demanding in terms of parameter control and input material quality. In practice, its implementation should be preceded by a process feasibility analysis.

Application Approach – Welding Laboratory

In practice, an increasing number of companies choose to conduct tests in specialised laboratories that allow real conditions to be replicated and technology feasibility to be assessed.

RMA's welding laboratory in Gdynia offers the possibility of:

- testing laser welding of aluminium on customer materials,
- process parameter optimisation,
- joint quality analysis,
- assessment of technology suitability prior to production implementation.

Summary

Laser welding of aluminium is a technology with great potential in industrial production, but its effective application requires an engineering approach based on data and testing.

Of key importance are:

- control of process parameters,
- quality of material preparation,
- proper definition of the process window,
- prior technology validation.

Only when these conditions are met is it possible to achieve the stability and repeatability that are essential in series production.

Typical Defects in Laser Welding of Aluminium – Causes and Corrective Actions

Defect	Symptoms	Main Causes	Corrective Actions
Gas Porosity	Pores in the weld cross-section, reduced fatigue strength	· contaminants (oils, moisture), unstable weld pool, excessive linear energy	· thorough surface cleaning, parameter optimisation (P/v), improved shielding gas coverage
Lack of Penetration (LOP)	Discontinuity through material thickness	· insufficient power, excessive speed, defocused beam	· increase power, reduce speed, correct focal position
Excessive Penetration / Burn-Through	Material perforation, edge deformation	· excessive linear energy, insufficient speed	· reduce power, increase speed, correct focusing
Hot Cracking	Micro-cracks along the weld axis	· unfavourable alloy composition, high shrinkage stresses, improper thermal balance	· select appropriate filler material, optimise parameters, change joint geometry
	Keyhole Instability	· Variable penetration depth, spatter	· excessive or unstable power, incorrect focusing, material reflectivity · stabilise parameters, optimise focal point, select appropriate laser source
Weld Oxidation	Dull, grey surface, degraded properties	· insufficient shielding gas, gas turbulence	· increase gas flow, change nozzle / feed direction, optimise gas (e.g. Ar, He)
Excessive Spatter	Irregular weld face, surrounding contamination	· unstable weld pool, excessive energy, contaminants	· reduce linear energy, improve cleanliness, stabilise process
	Component Distortion	· Geometry change after welding	· excessive heat input, lack of fixturing control