Manufacture of C-profiles and production of 3× 100 m empty jacket for laser welding demonstration

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January 16th, 2026

Demonstration of a stable laser welding process

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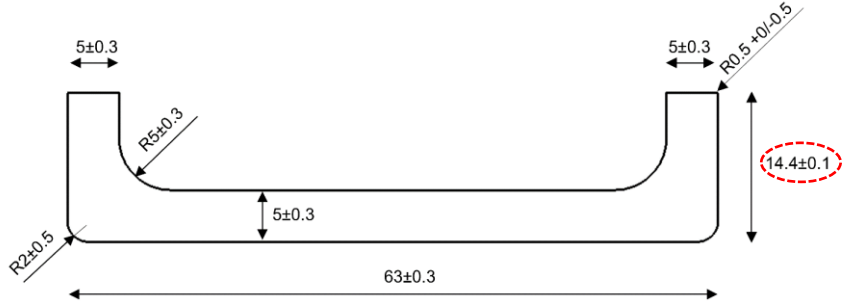
- The **laser welding contract with ICAS** (MAG-T.02.01-T002-D002) achieved several important accomplishments:
  - Butt-welding (production and QA),
  - Handling of 2×2×500-m-long C-profiles,
  - Synchronization of the machines in the assembly line.
- However, the crucial goal of that contract (developing a **reliable and stable laser welding process** for long lengths) was **not achieved**.
- The goal of a **task in 2025** was to **demonstrate a stable laser welding process.**
- Two deliverables:
  - **MAG-T.02.01-T004-D001: Production of the required steel profiles** at **KAMET** in February 2025 https://idm.euro-fusion.org/?uid=2SVLXM
  - **MAG-T.02.01-T004-D002: Laser welding of multiple 100-m-long segments** at **Montanstahl** in July 2025 https://idm.euro-fusion.org/?uid=2SVM23

Production of the steel profiles at KAMET

- The requested profiles are relevant for **the production of the insert coil conductor (RW6)**



Cross-section: ~418 mm^2

Linear weight: ~3.34 kg/m

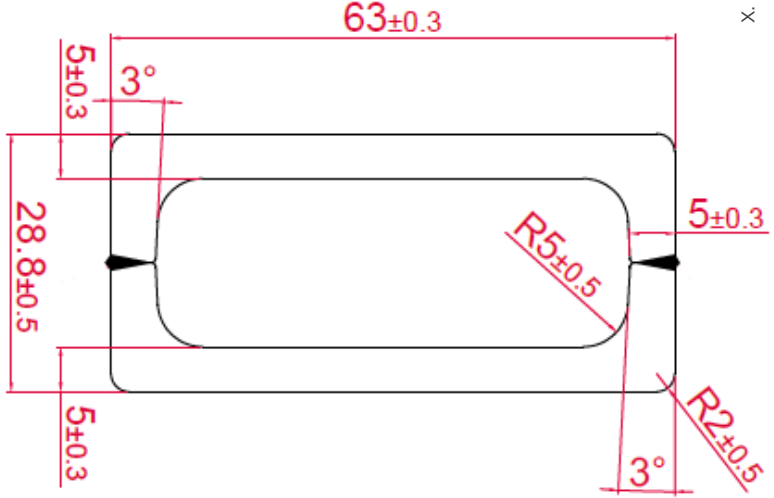
- Production by **hot rolling** + final **machining** step to obtain the tolerances on the vertical wings.
- The requested production was ~5.3 tons. The final production was unfortunately ~23% shorter:

Profile (ref)	Bundle (#)	Material	Heat	Length (m)	Weight (kg)
KY2179-A	1	W.1.4404	R30561	129	455
KY2179-A	2	W.1.4404	R30561	168	593
KY2179-A	3	W.1.4404	R30561	329	1,160
KY2179-A	4	W.1.4404	R30561	283	1,000
KY2179-A	5	W.1.4404	R30561	193	680
KY2179-A	6	W.1.4404	R30561	133	470
			Total	**1,235**	**4,358**

- These steel profiles can be produced in **long-lengths** (might eliminate the need of butt welding!)

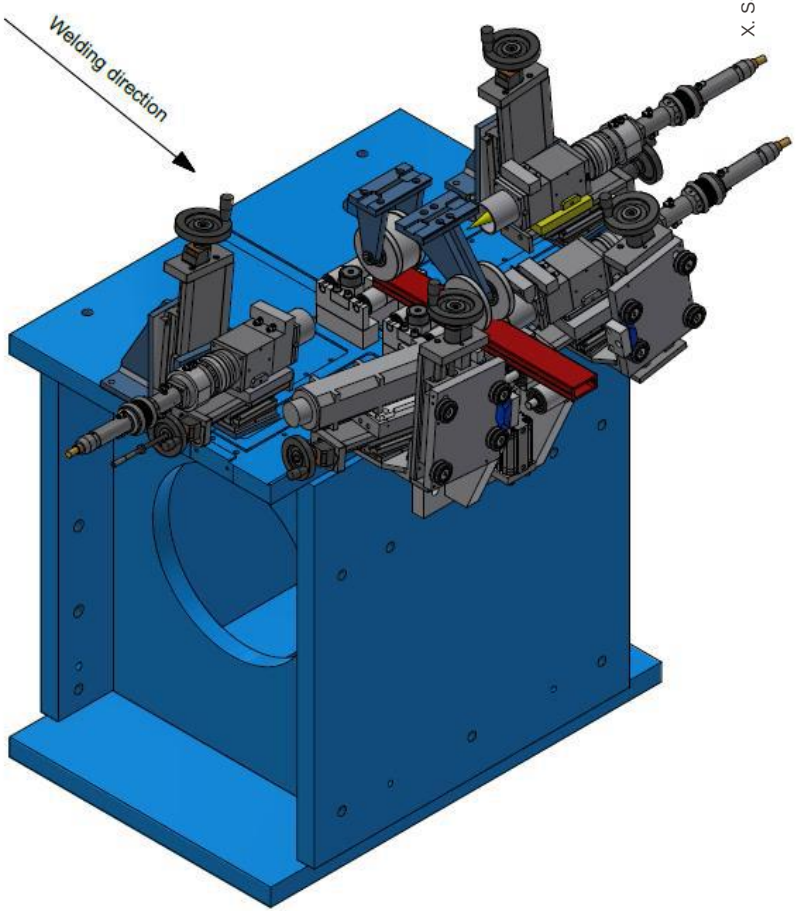
Laser welding. Goals

- Verify the technical feasibility of **full penetration, stable and reproducible laser welding on thick** (~5 mm) **long-length profiles** (≥100 m)
- Analyze the **weld quality** along the entire length, with particular attention to the presence of surface and volumetric defects.
- Confirm the ability to perform **controlled stops and restarts.**
- Investigate the possibility of local **repairs** and the quality and performance of the repaired zones.



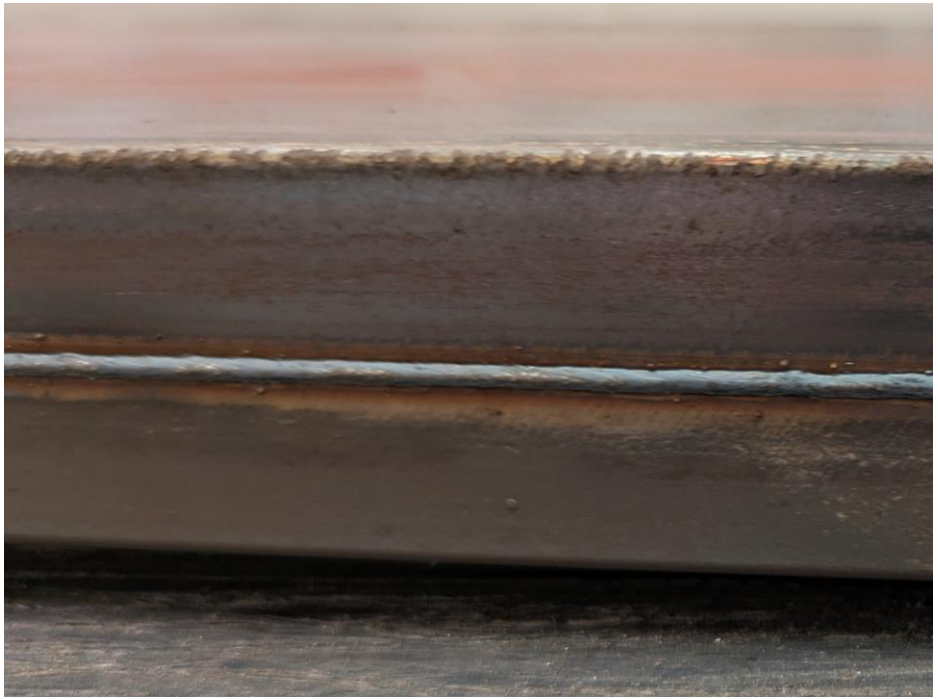
Laser welding. Approach at Montanstahl

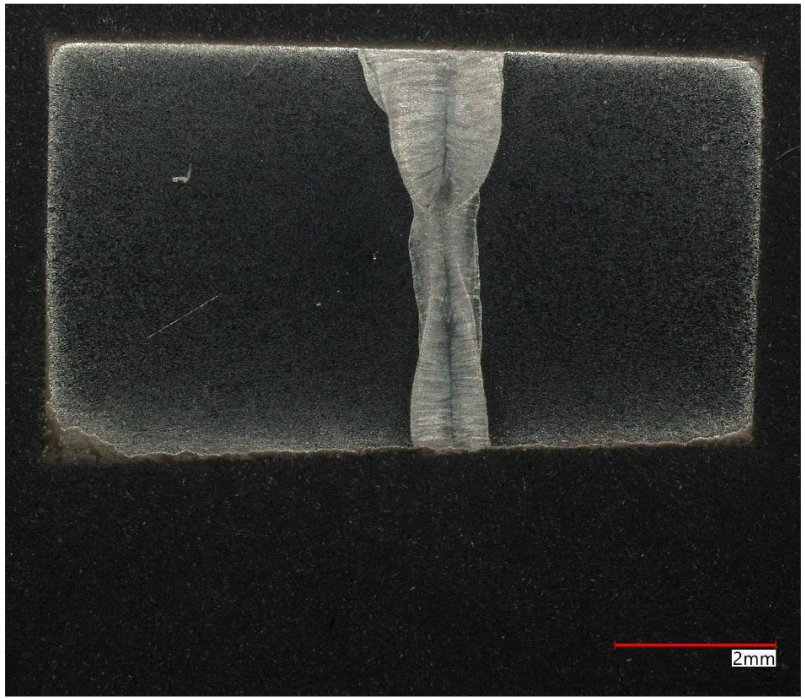
- **Three stages:**
  1. **8-m-long samples** – to characterize the material and determine the main process parameters: ~4 kW, ~2 m/min, no wobbling…
  2. **40-m-long sample** – validating the process on a semi-industrial scale.
     The weld quality improves if two welding passes are done:
     - An initial low-power (~1.0 kW) pass aimed at closing the gap between the C-profiles.
     - A second full-power (~3.7 kW) pass to achieve full penetration.
  3. **Production of the required 3×100-m lengths** – using the double-pass strategy:
     - Two pairs of lasers (one pair on each side) working synchronously.



Laser welding. Results

- Montanstahl's two-pass approach performed satisfactorily on 3×100-m-long profiles, with no severe defects observed.





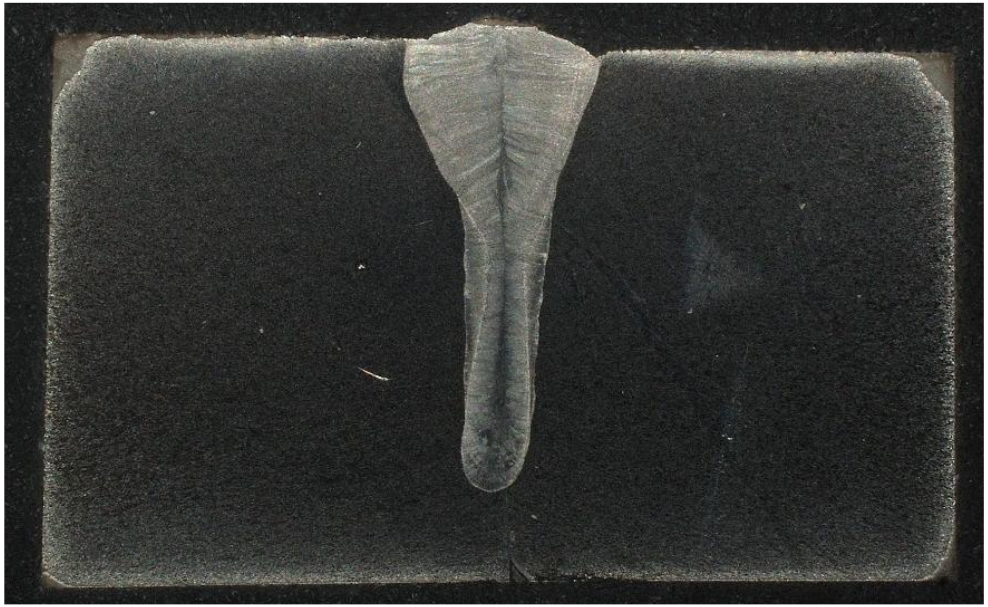
- However, there is room for improvement. Particularly on QA…

Laser welding. Quality Assurance

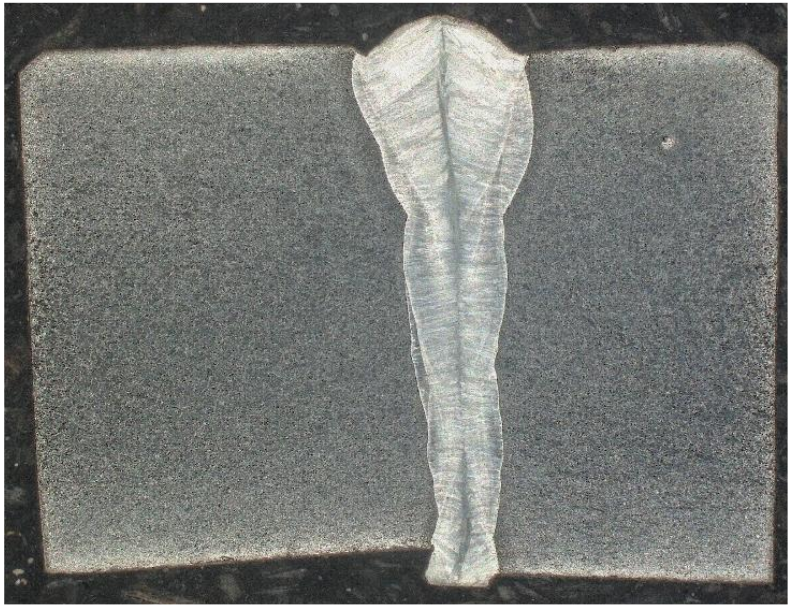
- **Online:**
  - **Visual inspection** (undercut, cracks, pores, incompletely filled groove, lack of seam)
  - **Ultrasound test** – phased array instrument M2M Multi2000 Pocket (lack of penetration, internal defects)
- **Offline:**
  - **Ultrasound test**
  - **Dye penetrant test** (cracks)
  - **Micrographic test** – destructive test using Keyence VHX-7000 digital microscope (wrong alignment of the steel shells, lack of penetration, porosity)
  - **Hardness** (Vickers Hardness) – testing hardness of steel, weld and heat-affected zone
  - **Dimensional inspection** – Werth ScopeCheck S optical machine (various lengths, thicknesses and radii)
  - **Mechanical tests** – Zwick Z100 testing machine (tensile tests).

Laser welding. Observed defects

- **Incomplete penetration** is considered a defect because it could act as an initial crack, which can grow over time.

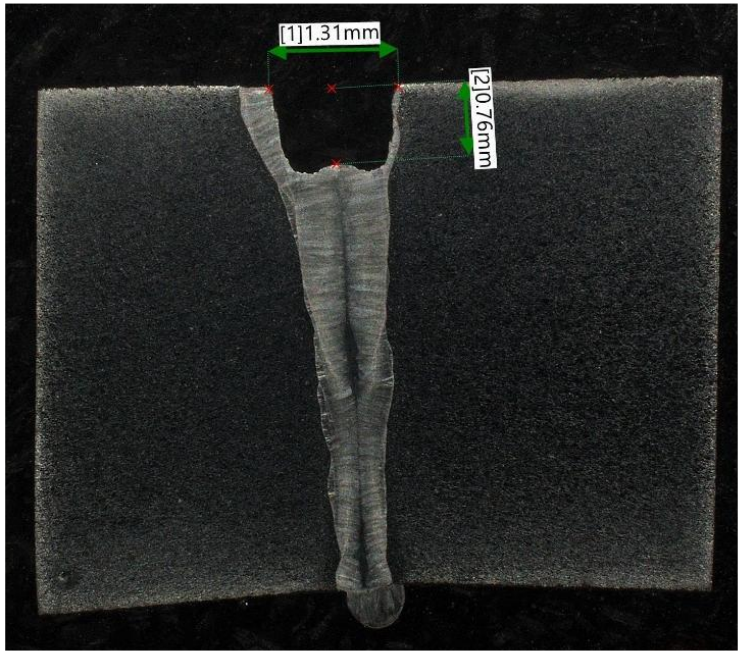


- **If detected**, incomplete penetration can be **reliably repaired** with an additional welding pass.

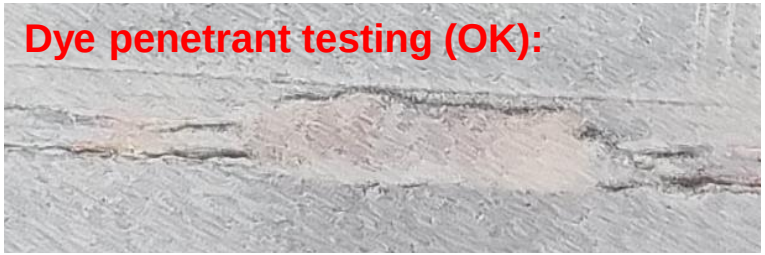


Laser welding. Observed defects

- **Incompletely filled groove**



- These defects can be **repaired by manual TIG.**



Laser welding. Ultrasound Testing (UT)

- The **initial laser welding parameters** resulted into full penetration during the first ~30 to 100 m, **but didn't achieve reliable full penetration along the entire length**
- When detected, these defects can be **reliably repaired**, and the line can be **safely stopped and restarted**.
- An (online) **NDT method is required** to reliably detect defects.
- **Montanstahl** used their **own UT inspection** system:
  - It could not detect lack-of-penetration defects ≤ 1.5 mm (too big)
  - **Further improvement is needed**:
    - a more sensitive UT system?
    - an alternative inspection method?

Conclusions

- **Production of the steel profiles (MAG-T.02.01-T004-D001):**
  - The C-shape steel profiles can be produced in **long-lengths** (>300 m)
  - This might eliminate (or significantly reduce) the need of butt welding
- **Laser welding of multiple 100-m-long segments (MAG-T.02.01-T004-D002):**
  - **Montanstahl's two-pass approach performed satisfactorily** on 3×100-m-long profiles (**no severe defects observed)**
  - When detected, defects can be **reliably repaired**, and the line can be **safely stopped and restarted**
  - Further **improvement** is **needed in the NDT inspection** method.
- **Next steps:**
  - **Industrial assembly and laser welding of the insert coil conductor (RW6)**
    - 100 m of copper dummy (highly desirable for trials)
      (new task for the procurement of the copper dummy required)
    - 100 m of reacted Nb_3Sn RW6 conductor