



## ***Structural strengthening of Rocket Nozzle Extensions by Means of Laser Metal Deposition***

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## **LASER METAL DEPOSITION**

- Presentation overview
- Motivation – The Vulcain 2/2+ NE Nozzle
- Overview of existing deposition technologies
- Laser Metal Deposition, LMD
- Equipment
- LMD features and properties
- Full scale verification

## **SUMMARY**

# Presentation overview



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## SUMMARY

# Task: Upgrade the Vulcain 2 engine



*Photo: Courtesy of ESA*



*Photo: Courtesy of Astrium*



# The Vulcain 2/2+ engine



## Vulcain 2 (Main engine of the Ariane 5)

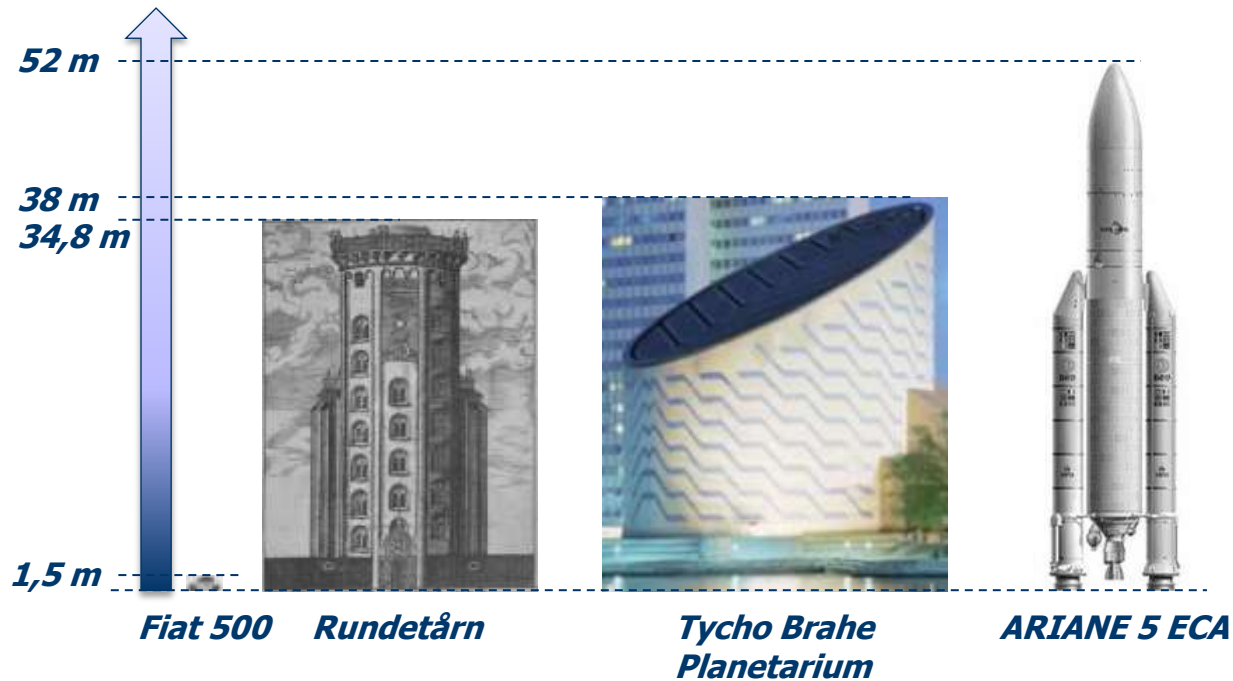
- Dimensions:  $\varnothing 2.1 \text{ m} \times 2.3 \text{ m}$  (7' x 8½')
- Weight: app. 400 kg (900 lbs)
- Thrust: 150 ton thrust (app. 6 mill. bhp)
- Fuel consumption: 250 kg/s (cryogenic liquid fuel)
- Flame temp.: app. 3000 °C
- Exhaust gas velocity: app. 4000 m/sec
- Coolant: Liquid H<sub>2</sub> at app. -240°C
- Engine life time: app. 10 min.

## Requirements

- Low weight, no deformation at extreme loads, high temperatures and temp. gradients



# The ARIANE 5 launcher – Size and scale



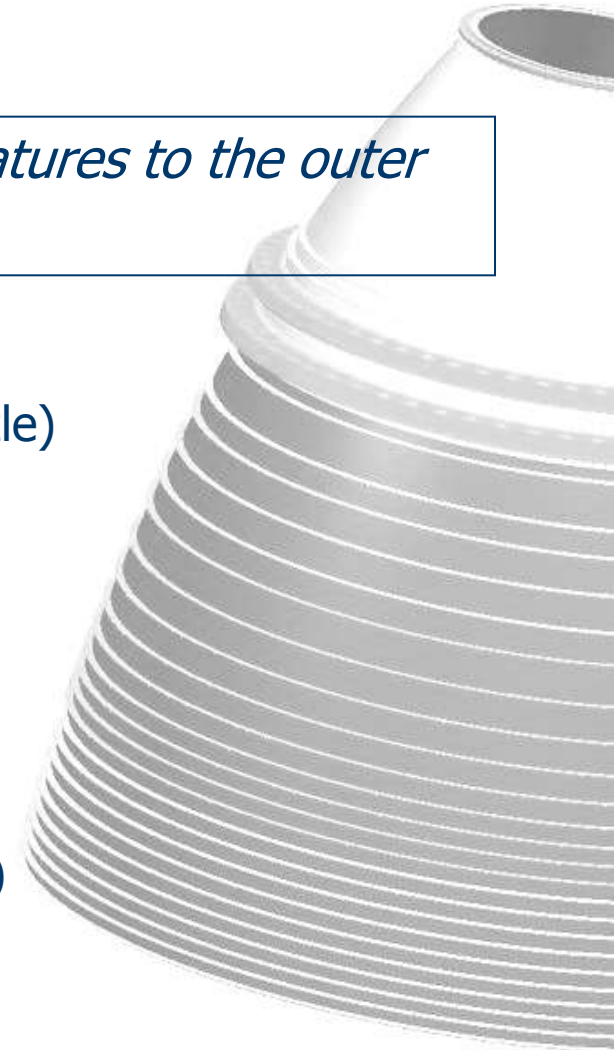
|                   | <b>Rundetårn</b>        | <b>Ariane 5</b>                             |
|-------------------|-------------------------|---------------------------------------------|
| Height:           | 34.8 m                  | 52 m                                        |
| Diameter:         | 7.68 m                  | 5.2 m                                       |
| Mass:             | 5,914 t                 | 777 t                                       |
| Horse power (BHP) | None<br>(since 2009...) | 6,000,000<br>(appr. 884,000 Fiat 500, 69HP) |

# The task: Why bother?

## Motivation:

*Devise a method for the application of 3D features to the outer face of a thin-walled structure*

- **Application:**
  - Strengthening/stiffening features (Rocket nozzle)
  - Weld preps (Rocket nozzle)
- **Constraints:**
  - Utilize existing laser weld cell
  - High deposition rate
  - Limited deformation
  - Limited penetration (no channel burn-through)
  - Multiple layer build-up (variable thickness)

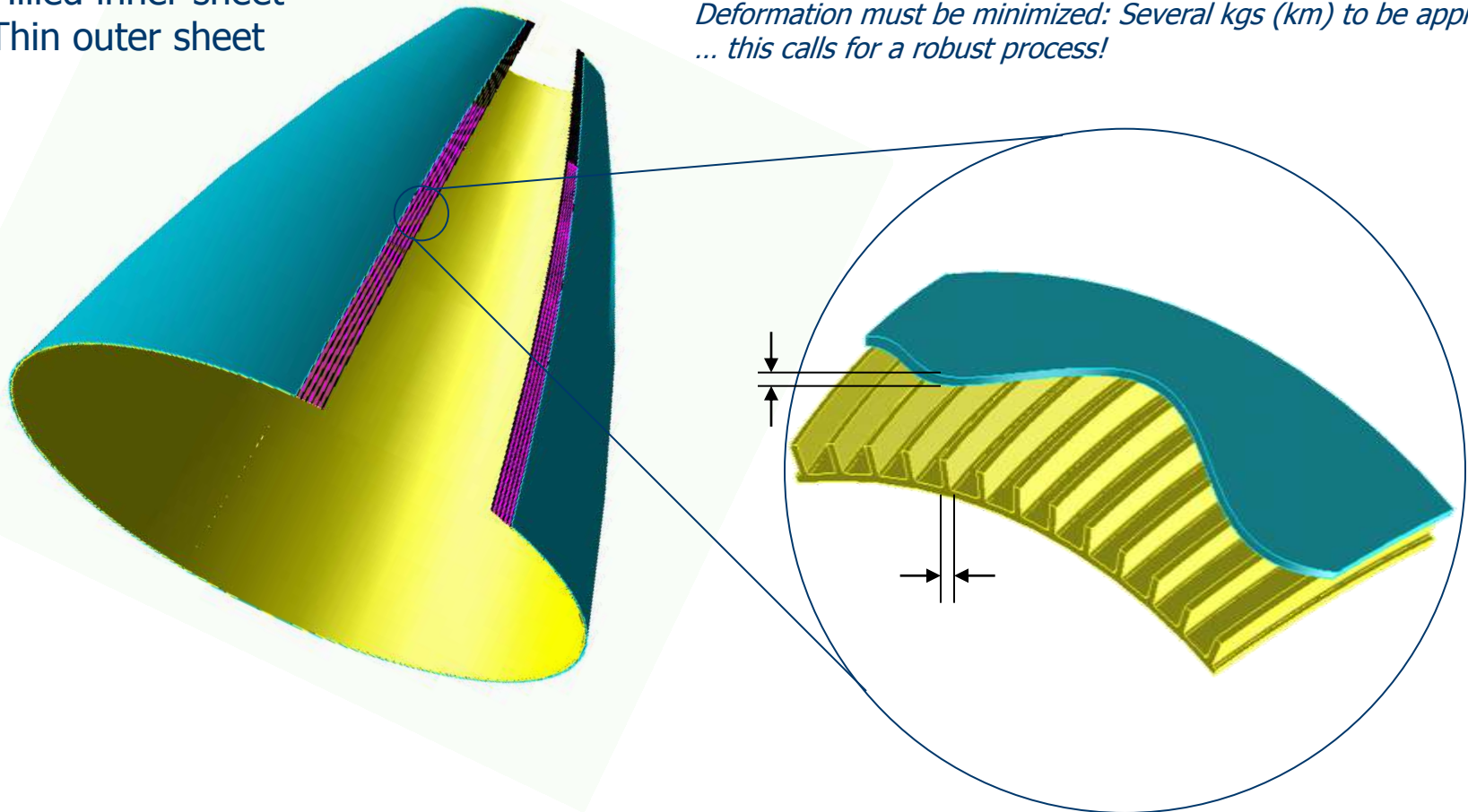


# Vulcain 2/2+ NE – Sandwich Concept

## SW-technology:

- Milled inner sheet
- Thin outer sheet

*Limited penetration required:  $t_{cs}$  is only app. 1 mm ...  
Deformation must be minimized: Several kgs (km) to be applied  
... this calls for a robust process!*





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# Motivation – Why develop a new process?



## Characteristics of common cladding processes:

- High heat input
- Several layers required due to high dilution
- Severe thermal deformation
- Multiple steps (some processes)

## Motivation

- Single step
- Low Q/deformation
- High dep. Rate
- High robustness



- **Study: Alternative MD methods**

- **TIG (GTAW)**

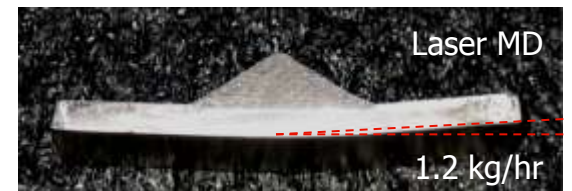
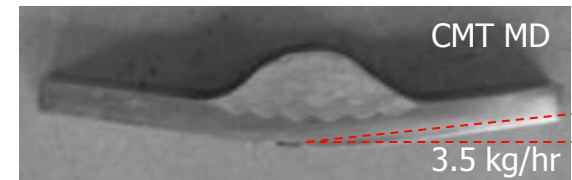
- Heat input high
    - Build rate ok (app. 500 g/hr expected)

- **CMT (Cold Metal Transfer)**

- Heat input high (app. 50% of TIG)
    - Penetration high (app. >0.8 mm)

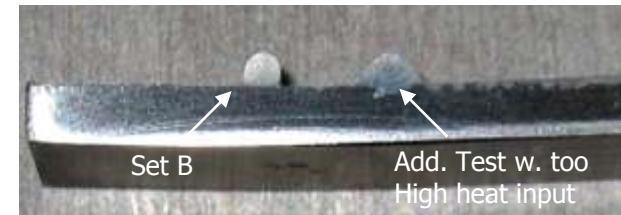
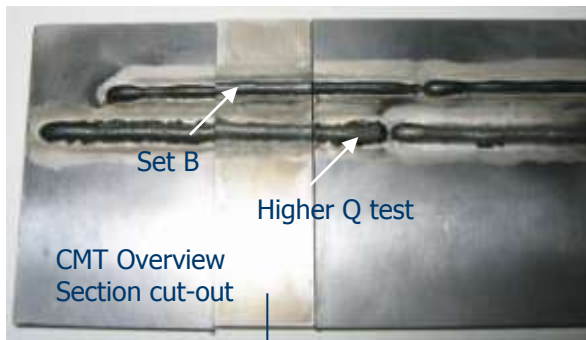
- **Diode MD**

- Similar in process properties to laser MD
    - Wider track potential (increased dep. rate)



# Heat induced deformations: CMT

## Is CMT the way to go?



↑  
*Severe deformation!*



# Deposition processes – Properties



## Deposition methods overview

|             | Power       | Velocity   | Heat input | Dep. rate | Layer thickness | Penetration | Dilution | Process steps |
|-------------|-------------|------------|------------|-----------|-----------------|-------------|----------|---------------|
|             | [kW]        | [mm/min]   | [kJ/mm]    | [kg/hr]   | [mm]            | [mm]        | [%]      | #             |
| GMAW        | 5 – 6       | 100 - 300  | 0.80-2.90  | 4 - 5     | >1.0            | 0.5 – 1     | 50       | 1             |
| GTAW        | 0.48 – 0.96 | 150 - 250  | 0.12-0.38  | <0.5      | >0.6            | >0.2        | ~50      | 1             |
| CMT         | 0.85 – 1.7  | 600 - 1600 | 0.04-0.08  | 1.1-3.0   | >1.0            | ~0.8        | ?        | 1             |
| Laserfusing | 3,5         | <500       | ~0.40 a)   | b)        | 0.5-0.7         | 0.1-0.2     | 10-20    | 2             |

- a): Laser heat input is severely reduced by reflection. Actual heat input to the work piece is expected to be 10-50% lower. The laser is projected in a track several mm wide. The irradiance ( $W/mm^2$ ) is therefore limited.
- b): Deposition rate depends on thermal spraying process. Laserfusing is a two-step process.

## Laser Metal Deposition

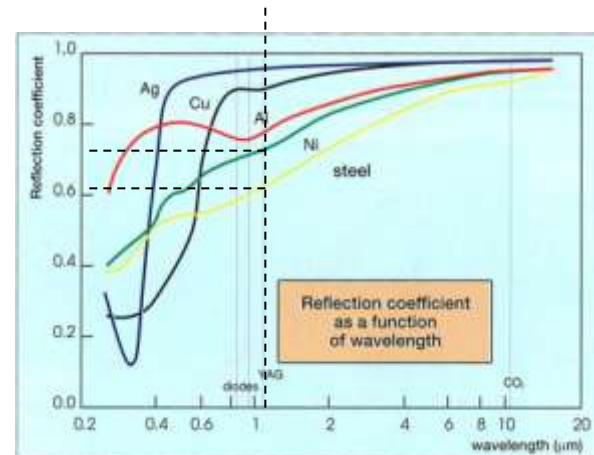
|     |       |             |                 |      |          |            |                 |   |
|-----|-------|-------------|-----------------|------|----------|------------|-----------------|---|
| LMD | 2 – 4 | $\geq 2000$ | 0.07-0.12<br>c) | <1.5 | 0.25-0.5 | 0.15 – 0.5 | ~30<br>Estimate | 1 |
|-----|-------|-------------|-----------------|------|----------|------------|-----------------|---|

- c): LMD heat input is severely reduced by reflection. Actual heat input to the work piece is expected to be 10-50% lower.

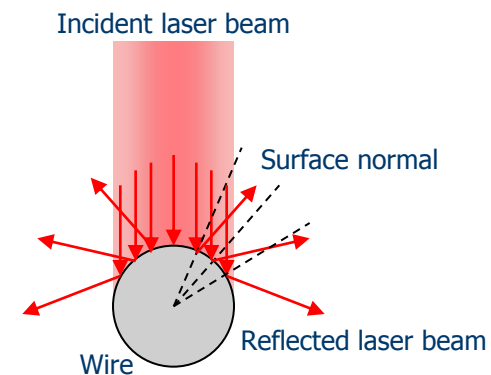
# Why is the LMD heat input so low?

- **Mechanisms lowering the heat input**

- Fast process  
Process speed: several m/min
- Reflection off of surface is high  
No key-hole process
- Reflection off of the curved wire surface reduces actual heat input to work-piece  
Snell's law:  
*Angle of incidence = exit angle*  
(Same as in billiards)
- Result: Virtually *no* heat induced deformation



(Source: J.F. Ready, Industrial Application of Lasers, Academic Press, New York, 1978)



# Presentation overview

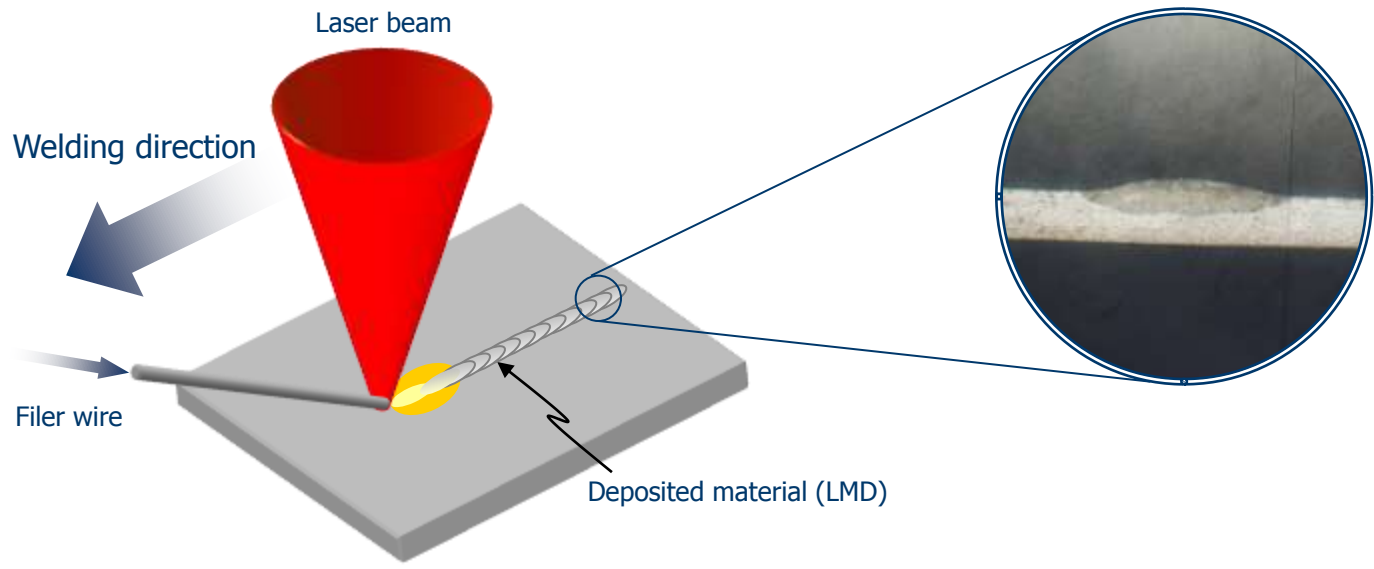


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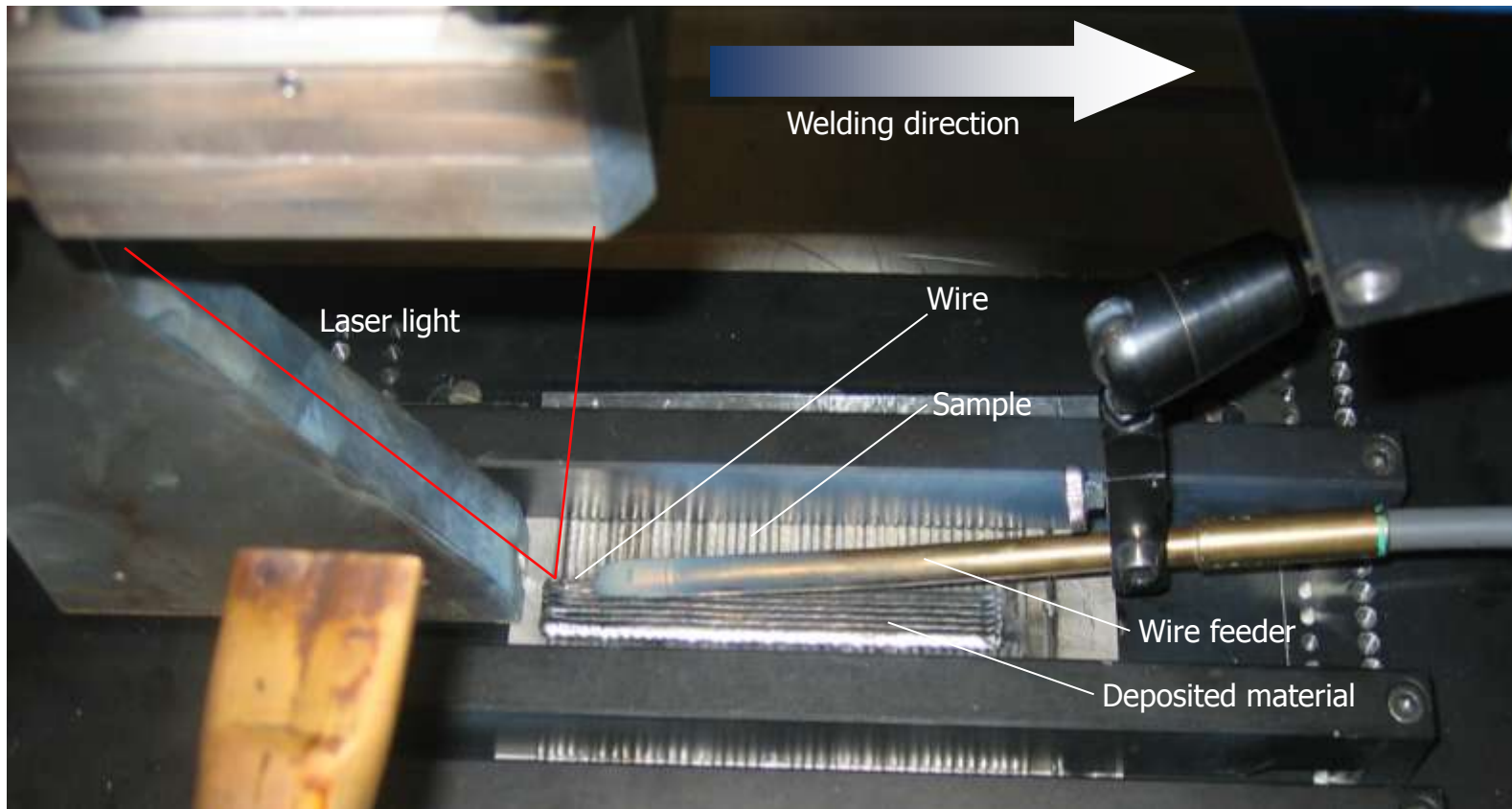
## **SUMMARY**

# LMD – The process explained

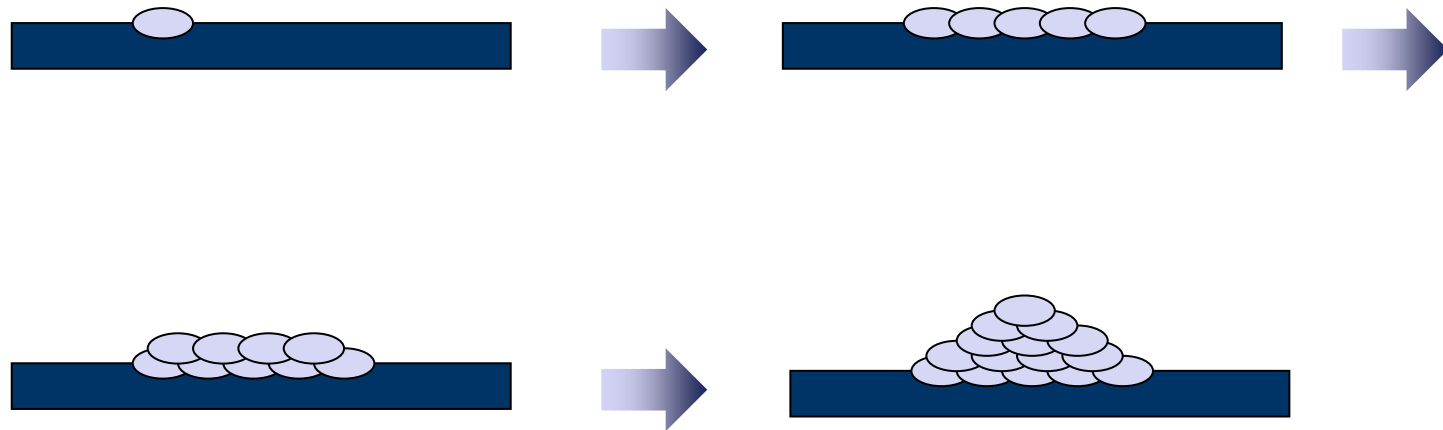




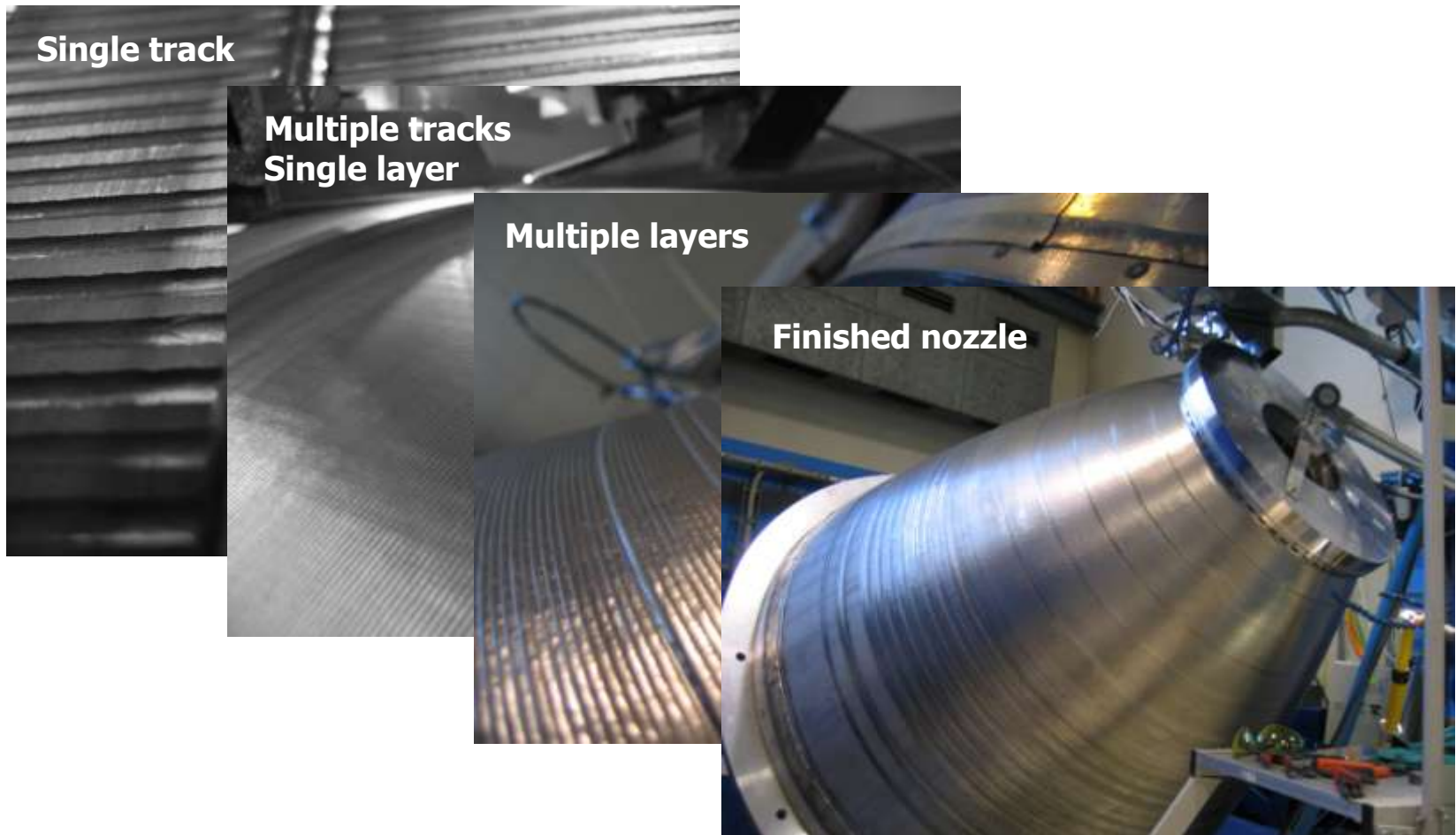
# Process close-up



# Deposition strategy



# Application strategy



# Presentation overview

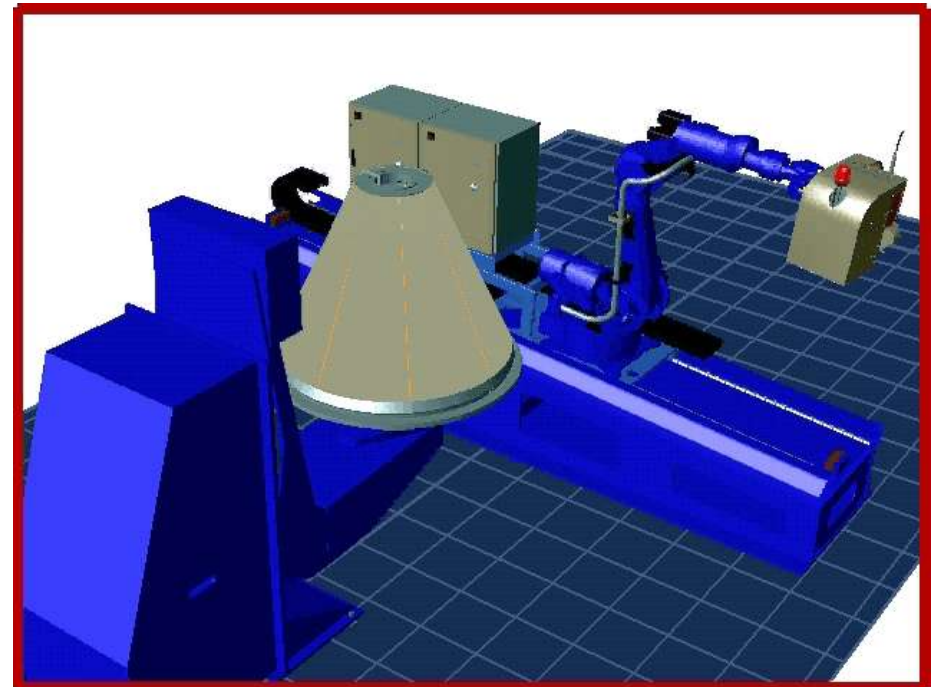


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## SUMMARY

- **Laser**
  - TRUMPF HL4006D
  - 4 kW Nd:YAG with fiber delivery
  - Custom optics
- **Wire feeder**
  - Migatron standard
  - From regular welding machine
  - Controllable start/stop, feed rate
- **Manipulator**
  - x,y,z and/or rotational
    - LASMA laser weld cell
    - Robot weld cell rotiter: 5,000 kgs max.

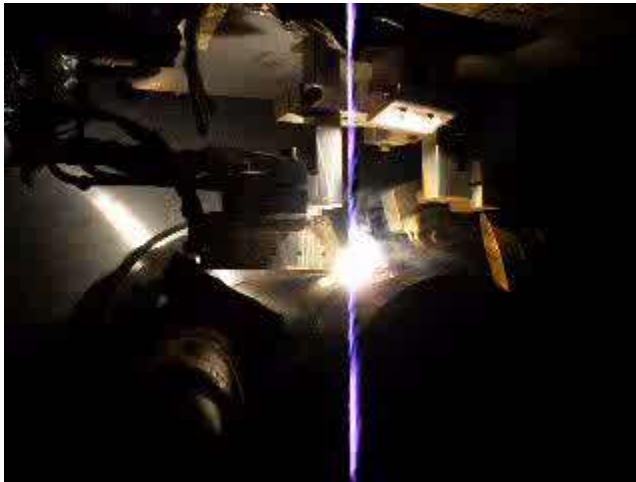


# The LMD process (Sample pipe)



## Laser Metal Deposition

- Keywords
  - Limited heat input (and deformations)
  - High deposition rates
  - No spatter
  - No defects
  - Limited fume generation



# Presentation overview



## LASER METAL DEPOSITION

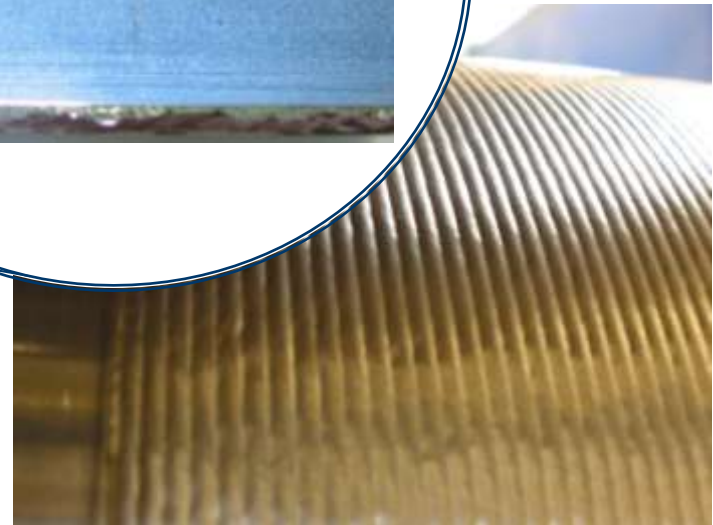
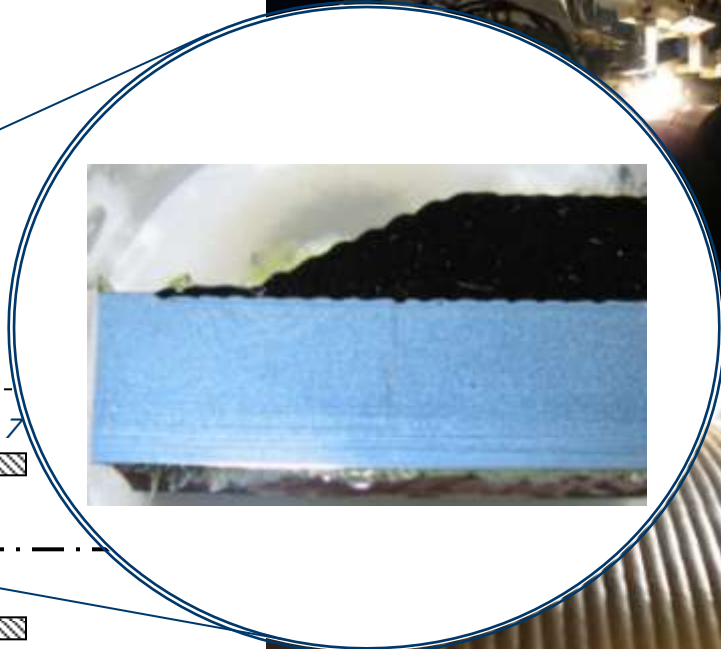
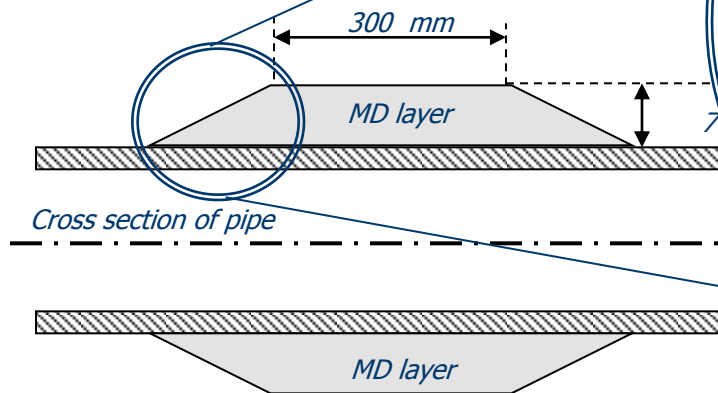
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# Example: Pipe-sleeve

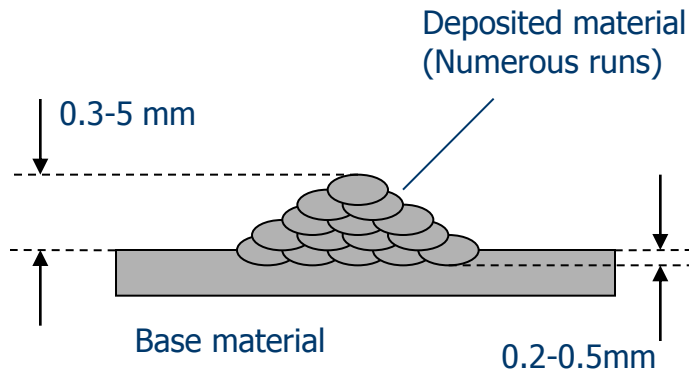
## Pipe sleeves

- Outer reinforcements (Duplex)



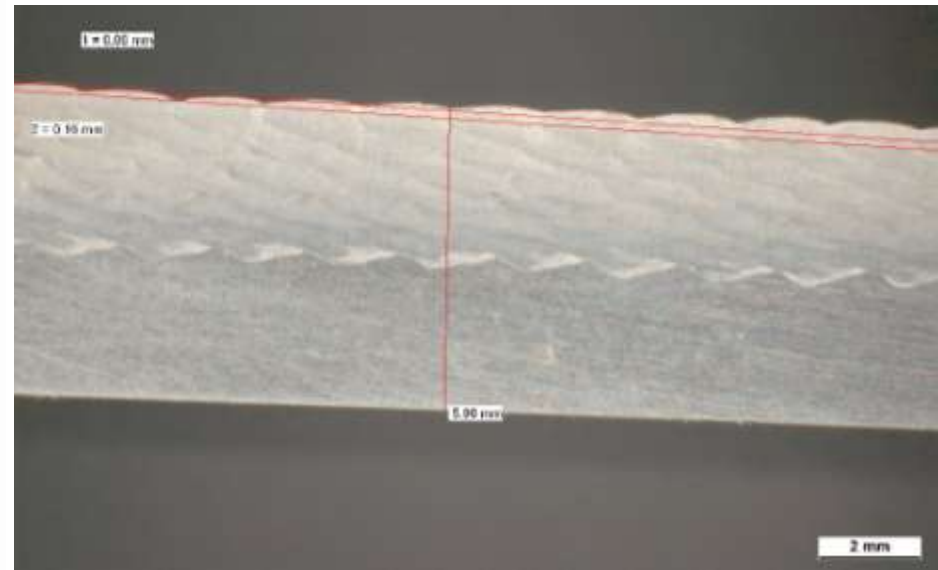


## Requirements and results



| Requirement /preliminary                          | Target                                  | Experimental results         |
|---------------------------------------------------|-----------------------------------------|------------------------------|
| Penetration into the Sandwich Wall, (Outer Shell) | < 0.5 mm<br>(Recommendation 0.2-0.5 mm) | <b>0.2 – 0.5 mm</b>          |
| Build rate                                        | > 350 g/hr                              | <b>&gt;1100 g/hr</b>         |
| Thickness variation                               | < $\pm 5\%$                             | Very smooth surface topology |
| Pores and inclusions                              | < 0.2 mm                                |                              |
| Surface condition                                 | Free from cracks and oxides on surface  | No visual surface defects    |
| Total thickness of deposited material             | > 0.3                                   | 0.25 – 20...                 |

# Experimental results – Surface quality



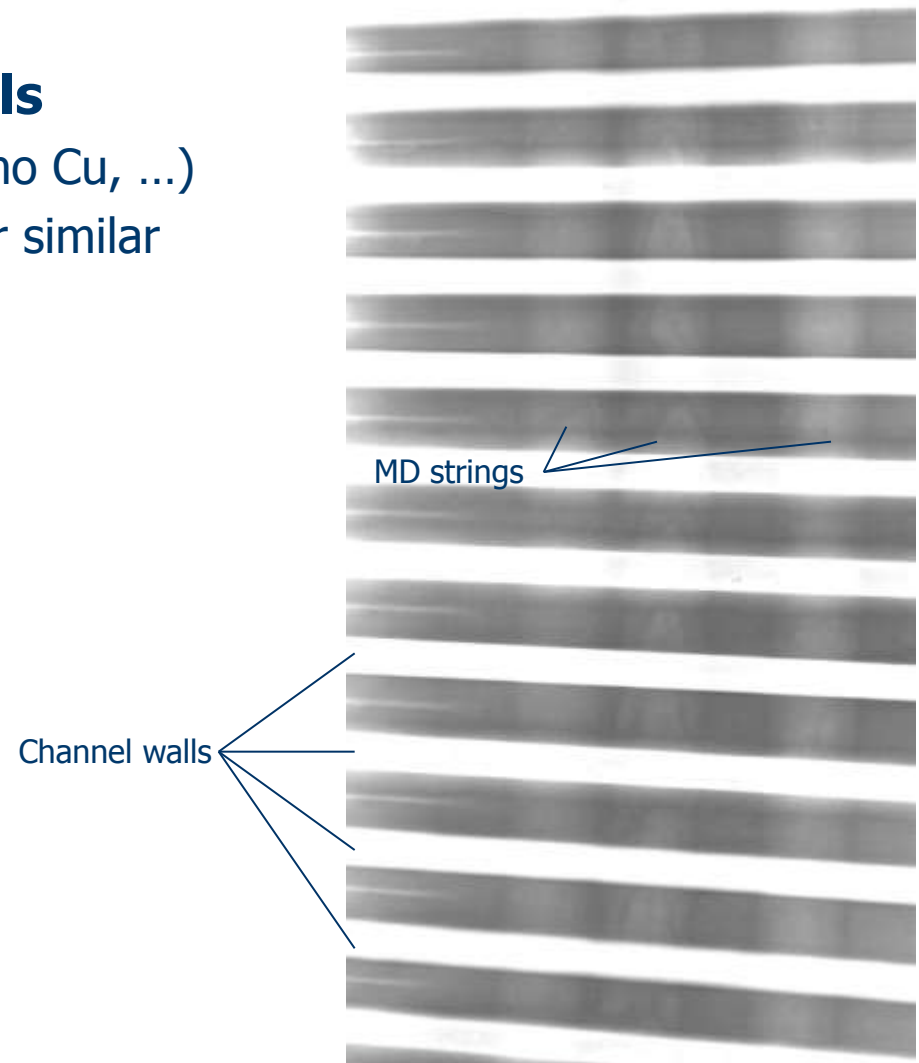
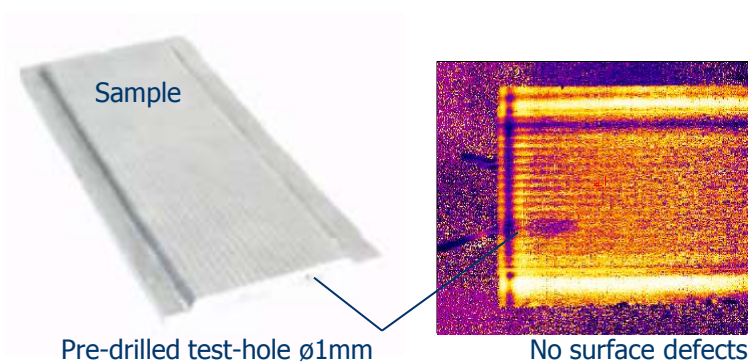
## **Example:**

LMD on 3.17 mm thick base plate, 10 layers applied.  
Surface waviness: Approx. 0.16 mm

## **Characteristics:**

No pores or inclusions observed  
Limited penetration/dilution/HAZ

- **Surface requirement details**
  - Not too shiny (not polished, no Cu, ...)
  - Simple cleaning w. ethanol or similar
- **Observations**
  - No surface defects
  - No volume defects (Digital x-ray verification)



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# Engine test facility (DLR)



# Full-scale test-run (at DLR)



>15,000 m of LMD  
>90 kgs  
Power: 100%  
Duration: 12 minutes



# Engine test - Video



Playback  
Time: 1:56

Engine test December 22<sup>nd</sup> 2009 successful!





## Requirements

- Pre-treatment/requirements
  - Clean
  - Free of oxides
- Post treatment
  - None
  - Grinding/honing
  - No cracks, inclusions, pores or other defects

## Applicable materials

- Wire shaped materials can be applied, e.g.
  - Inconel 625
  - Stellite 6
  - Duplex steel
  - ... other wire-based
- Sandwich layers possible
- Band-shaped material (increase in dep.rate)

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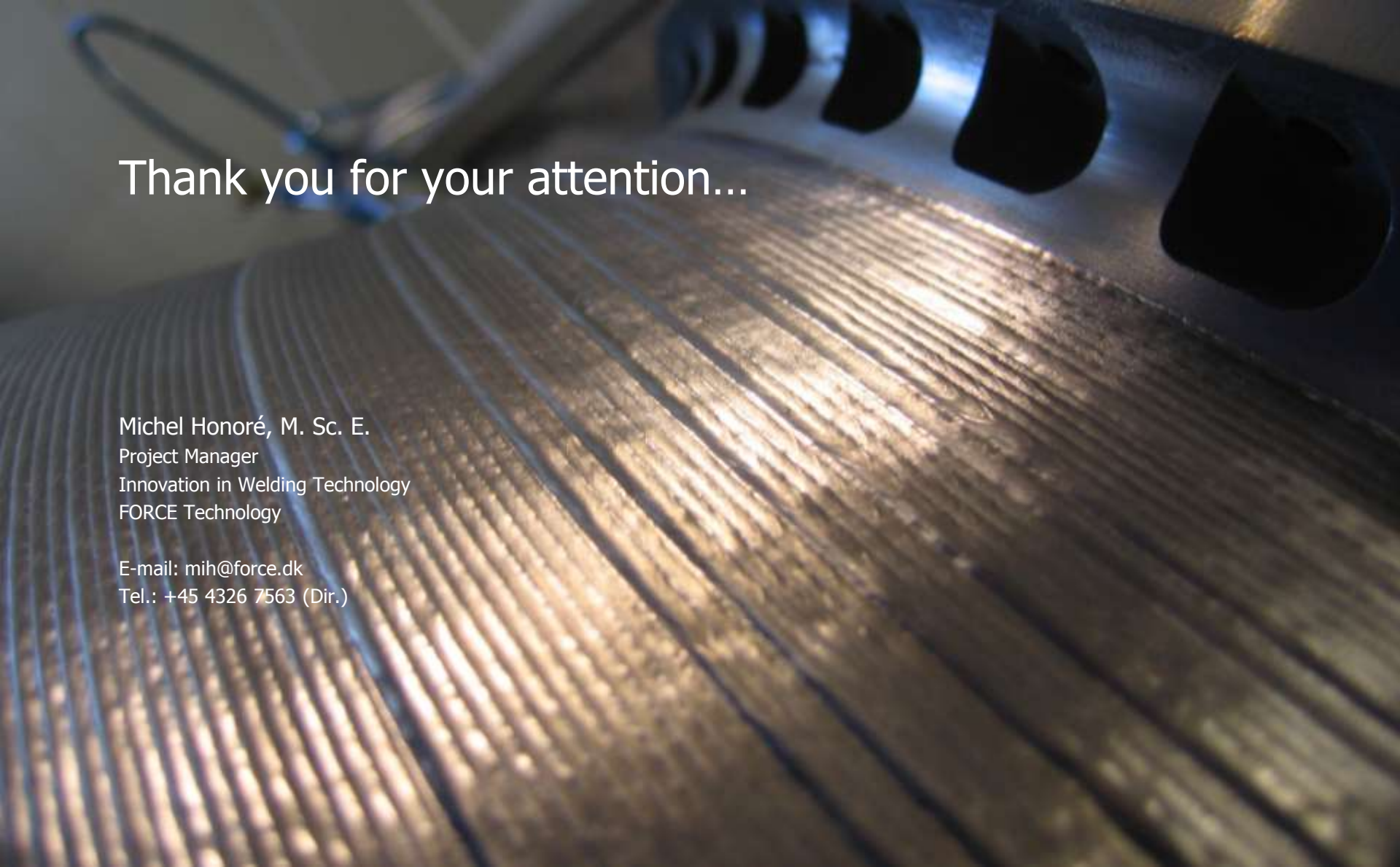
# Summary – Laser Metal Deposition



## SUMMARY

- Surface: Fully welded (no porosity)  
No pores, inclusions or other volume defects  
Waviness <0.2 mm
- Thickness: 0.25 – 20+ mm layer
- Material: Potentially any alloy available in wire-form
- Parent mat.: Any metallurgically bondable alloy  
Not too shiny  
Cleaned with ethanol/similar
- Dep.rate: >1 kg/hr (potential for increase)
- Sandwich layers possible
- Limited heat induced deformations
- Limited post treatment



A close-up photograph of a metal surface with a prominent grid or ribbed pattern. The lighting is dramatic, highlighting the texture and creating strong shadows and highlights. In the upper right, there are some dark, curved shapes that appear to be part of a mechanical assembly.

Thank you for your attention...

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