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## Feasibility of laser cladding for tooling repair in aerospace manufacturing: an alternative to chrome plating


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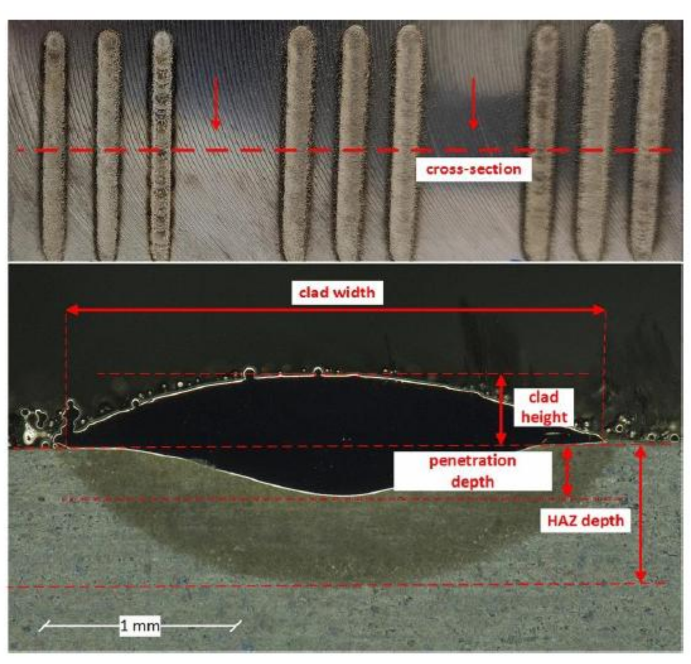
## Introduction

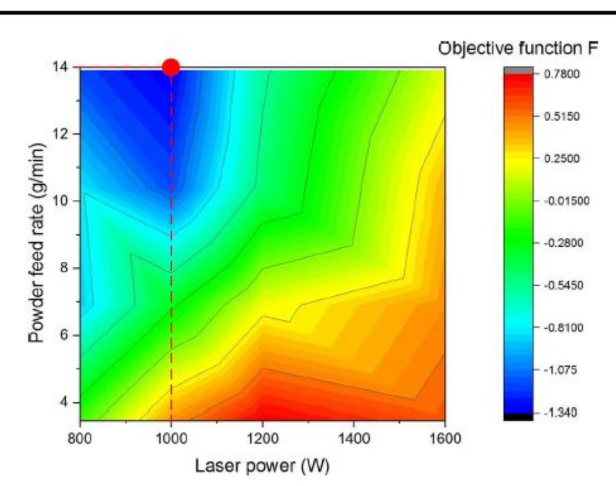
**Tooling plays a critical role in the manufacturing of nearly all components within the aerospace industry.** The materials used in this sector are often difficult to deform and tend to harden quickly during processing. Hard chrome plating has long been a widely used and trusted method for restoring worn surfaces—particularly cylindrical areas—on tooling. However, due to REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals) regulations, the use of chrome plating has been significantly restricted across EU countries. As an alternative, **laser cladding (LC)**—an additive manufacturing (AM) technique—offers a way to repair damaged components and enhance surface properties by applying advanced coatings. Since LC is a metallurgical process that produces a fully bonded coating, it shows strong potential for addressing many remanufacturing challenges in aerospace tooling.
The key question, however, is whether laser-cladded surfaces can be machined, ground, or finished using the same conventional methods as those used for hard chrome coatings.

## Laser cladding process and optimization

The laser cladding (LC) process parameters were optimized by developing an objective function F, which incorporated key factors (**cladding geometry, the heat-affected zone (HAZ), and coating hardness**). A comprehensive experimental design was implemented, consisting of 42 different parameter combinations. To better visualize the optimization process, a color map of the objective function was generated.



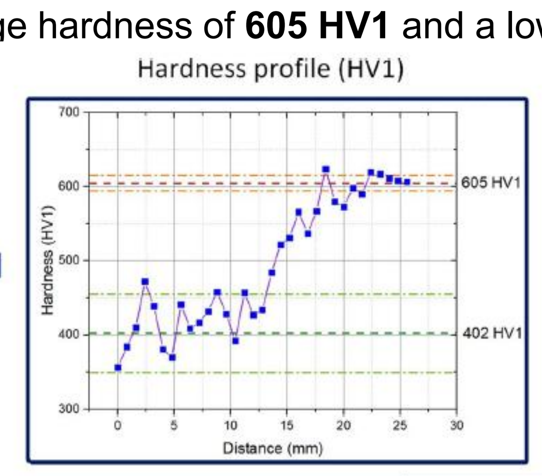

| | Variable process parameters | | Constant process parameters | | | |
|---|---|---|---|---|---|---|
| Name | Laser power | Powder feed rate | Laser diameter | Cladding speed | Carrying gas | Shielding gas |
| Unit | (W) | (g/min) | (mm) | (mm/s) | (dm³/min) | (dm³/min) |
| Level I | 800 | 3.5 | 3.5 | 10 | 4 | 10 |
| Level II | 1000 | 6.9 | | | | |
| Level III | 1200 | 10.4 | | | | |
| Level IV | 1600 | 13.9 | | | | |

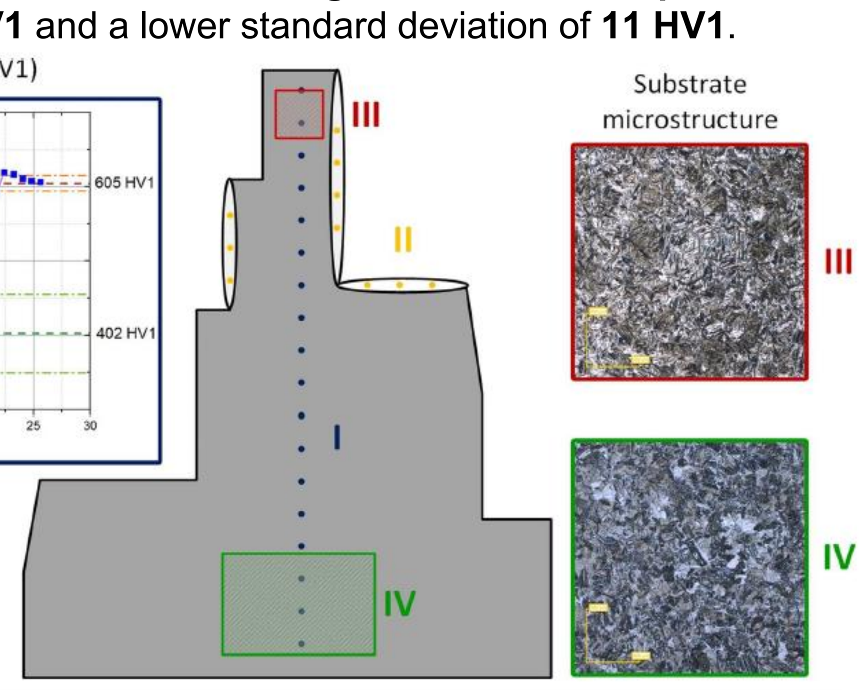



$$\min\{F(h_{clad}, d_{pen}, d_{HAZ}, HV0.3)\} = \min\left\{-\frac{h_{clad}}{h_{clad,max}} + \frac{d_{pen}}{d_{pen,max}} + \frac{d_{HAZ}}{d_{HAZ,max}} - \frac{HV0.3}{HV0.3_{max}}\right\}$$

## Microstructure analysis

A critical aspect of the microstructural analysis is assessing how the thermal input from the laser cladding process affects the microstructure of the 40HM substrate. **Hardness profiling** (indicated by blue data points) reveals significant variations in both microstructure and hardness, particularly in regions with smaller cross-sections that experience higher thermal input. The **green-marked area** is primarily composed of **ferrite and transformed martensite**, with an average hardness of **402 HV1** and a standard deviation of **53 HV1**. In contrast, the **red-marked region** contains **fine-plate martensite**, exhibiting a higher average hardness of **605 HV1** and a lower standard deviation of **11 HV1**.




Cladding hardness (HV1)

II

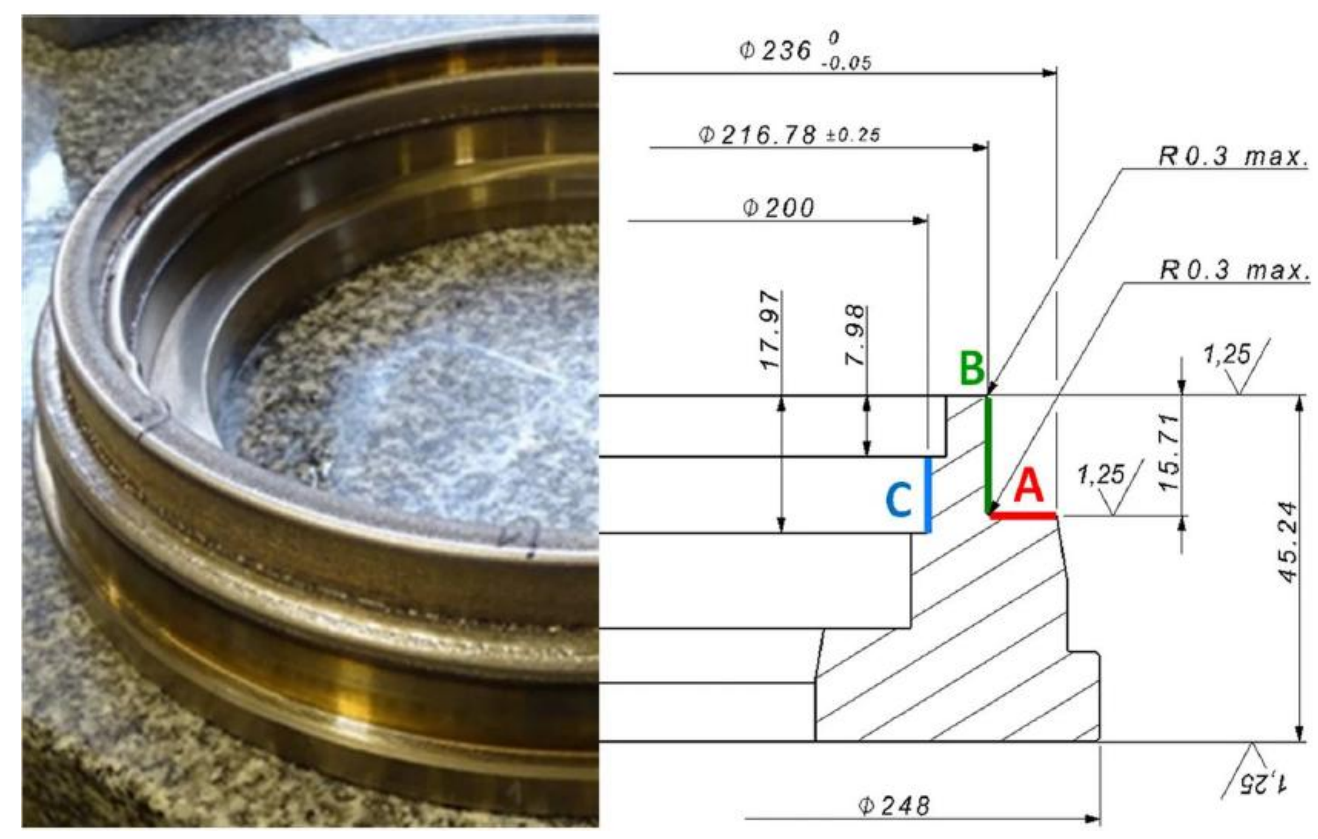
| | Mean | Std. dev. |
|---|---|---|
| Clad A | 754 HV1 | 66 HV1 |
| Clad B | 762 HV1 | 63 HV1 |
| Clad C | 727 HV1 | 31 HV1 |

## Postprocessing operations

The post-processing of the demo tooling involved several machining steps: initial frontal surface grinding, turning of the flat surface (**clad A**) and the external cylindrical surface (**clads A and B**), grinding of the external flat (**clad A**) and cylindrical surface (**clad B**), as well as milling and grinding of the internal cylindrical surface (**clad C**).
Following machining, **surface roughness** and **hardness measurements** were carried out using a dedicated industrial profilometer and Rockwell standard hardness testing equipment. All machines and tools used are part of the **Pratt & Whitney Kalisz Tool Room Department**, ensuring that the coating post-processing was performed under **real-world industrial conditions**.

## Demo tooling

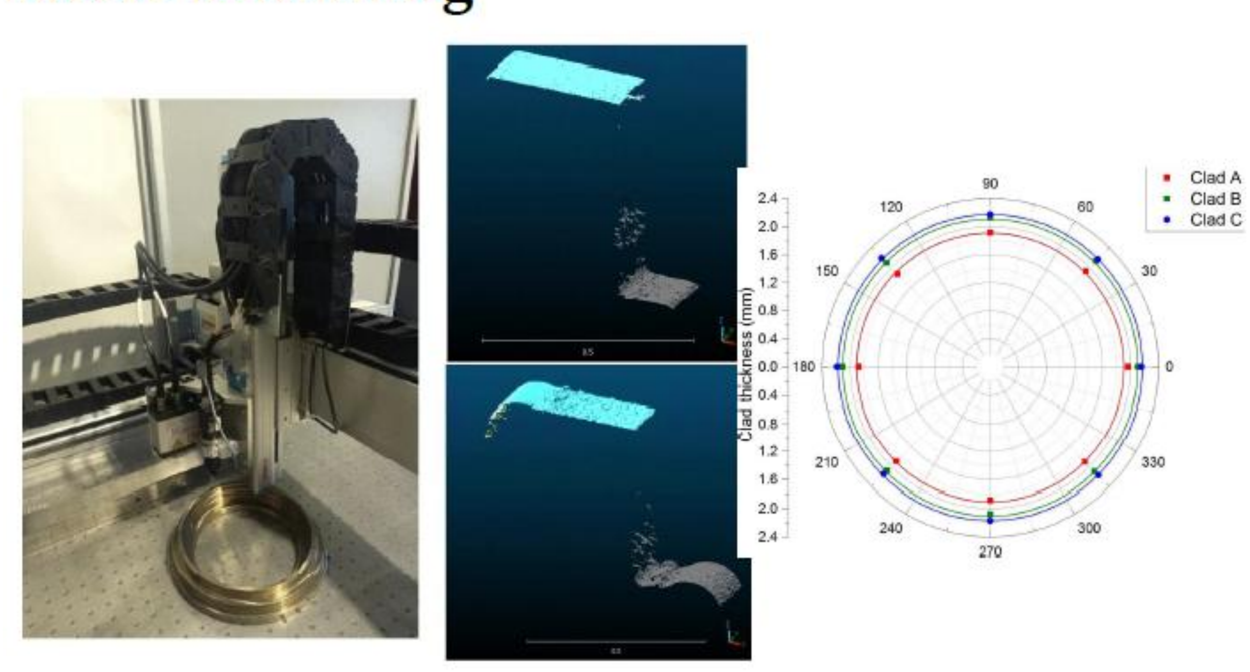
This investigation focuses on a **40HM steel ring**, a critical component used in machining aerospace parts on turning centers. To enable a comprehensive evaluation of the regeneration process for this demo tooling element, **three distinct surface geometries—A, B, and C—were selected for analysis**.



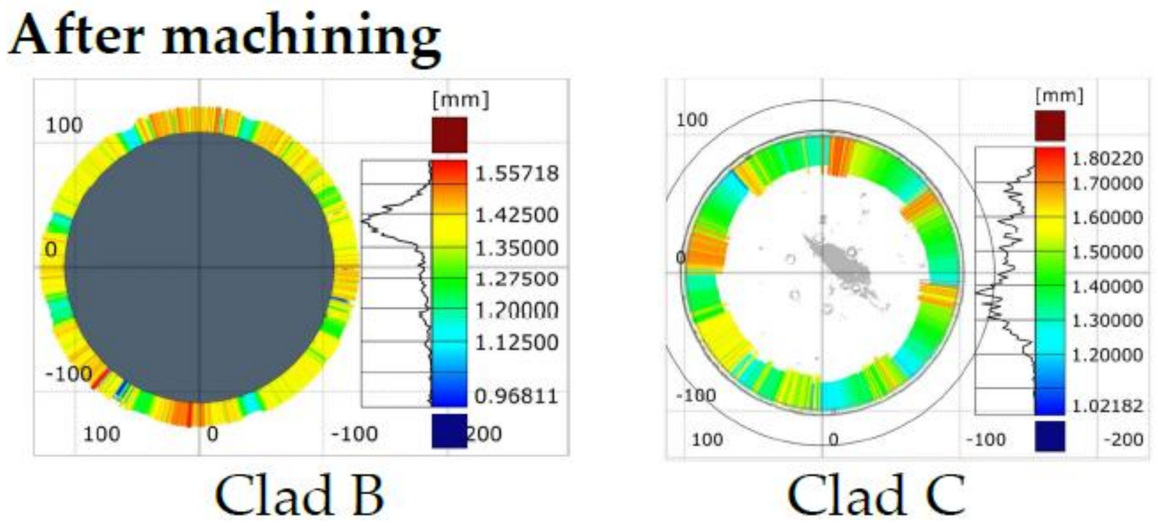

## Geometry scan

Before laser cladding (LC) deposition, surfaces A, B, and C were characterized using a **3D laser profilometer**, with measurements taken at **45-degree intervals**. The same measurement protocol was repeated after the LC process. Following machining, a **white light scanner** was used to assess the overall geometry. Scanning results confirmed coating thicknesses of approximately **2 mm before machining** and **1.5 mm after machining**.

Before machining




After machining




## Assessment of regenerative technology application

The analysis reveals that while the laser cladding (LC) process presents certain limitations—such as **reduced machinability** and a **propensity for defect formation during post-processing**—its **low environmental impact** makes it a strong candidate to replace hard chrome plating in aerospace tooling applications. Key findings include:
- **Environmentally sustainable alternative** to chrome plating, offering **comparable technical performance**
- **Feasibility of achieving** the required **coating thickness, hardness**, and **post-processing quality**
- **Potential applicability** of LC technology beyond **ring-shaped or axisymmetric components**

| Process | Chrome plating | Laser cladding |
|---|---|---|
| Cost-effectiveness | Medium for single pieces, better for mass scale (>5 pcs.) | High for single pieces, not recommended for mass production |
| Machinability | Limited (grinding and thin layers only <1 mm) | Limited (grinding only), less limitations because of thicker layers (> 1 mm) |
| Environmental impact | Chromic acid is carcinogenic and has been banned in the EU since 2017. Only short-term, single uses are permitted | No significant negative effects on the environment |
| Application | All surfaces | Just surfaces with good access |
| Typical defects | 1. Bubbles - 1 per 20 pcs., 2. Delamination - 1 per 50 pcs., 3. Peeling - 1 per 100 pcs. | 1. holes, 2. starches, 3. peeling -> insufficient data for statistical analysis |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