INSIDE Metal Additive Manufacturing

Postprocessing

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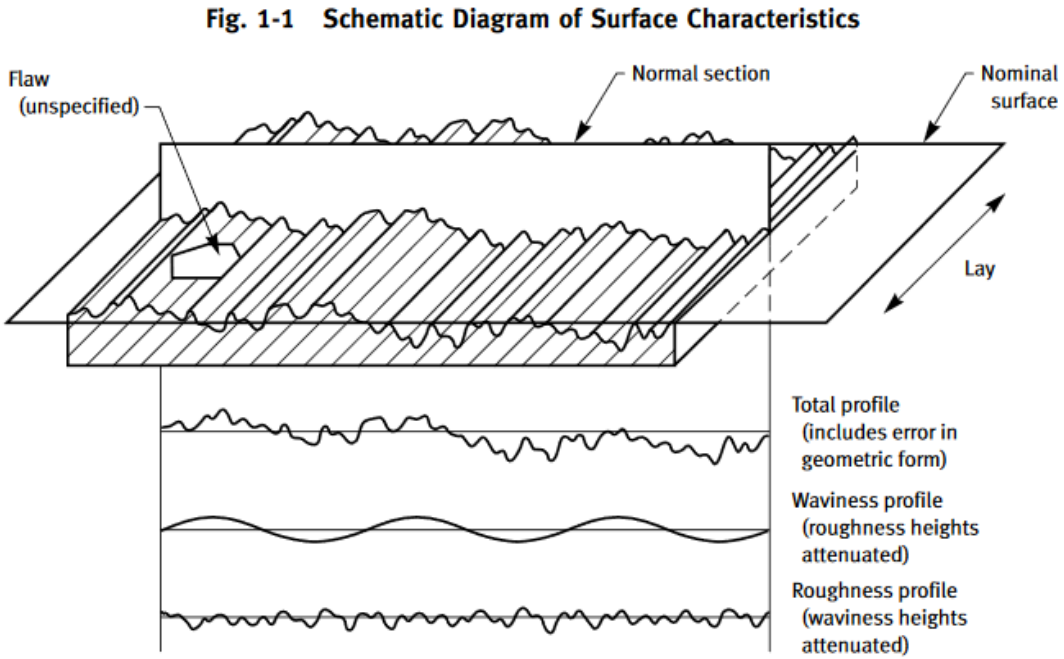
Short introduction to surfaces of SLM and LMD

Decomposition of the surface profiles



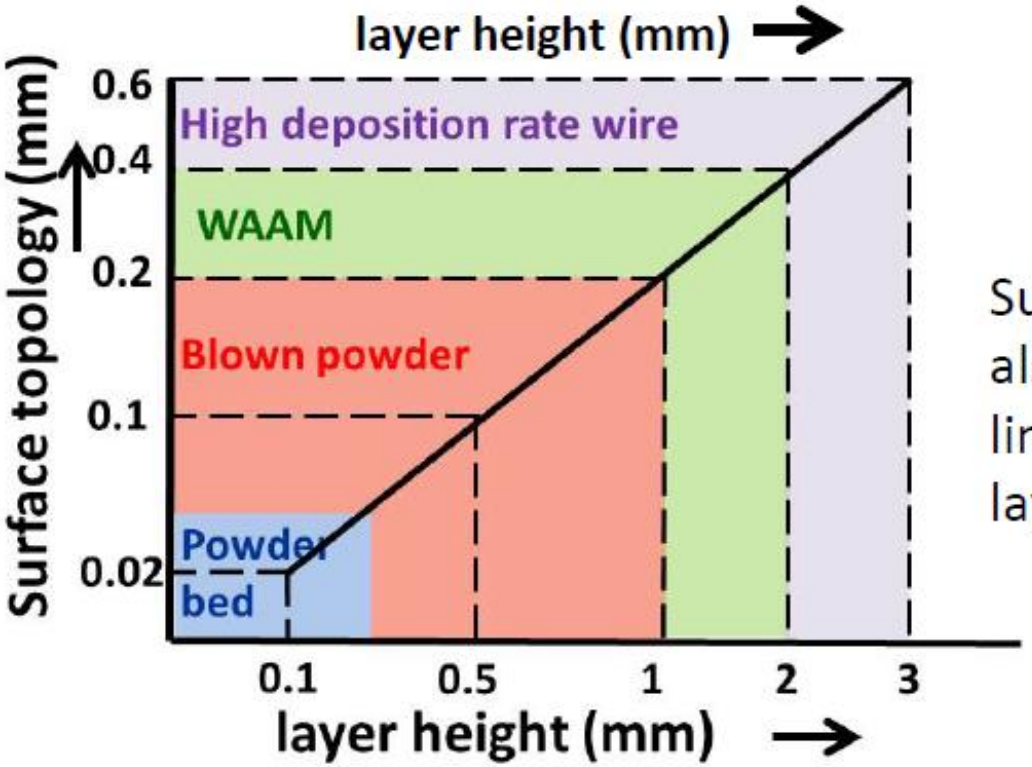
Profile
=
Waviness
+
Roughness

→ It is important to consider which components of the surface profile need to be removed and for what reason

→ ≠ AM technologies lead to ≠ surface morphology

Surface roughness is linked to technique

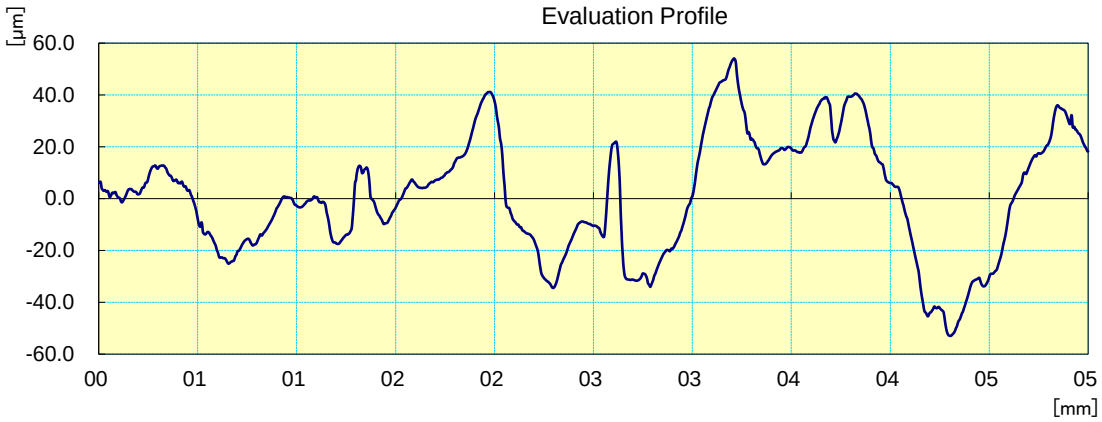
The thinner the printed layer and powder size, the smaller the surface features

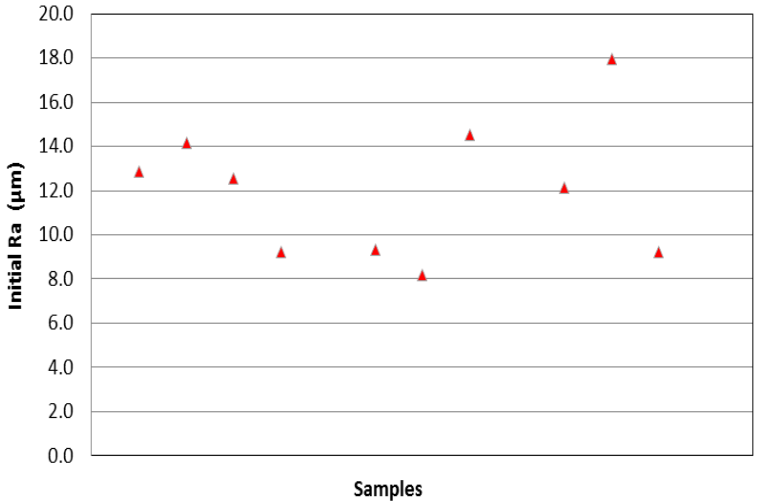


Surface finish also depends linearly on the layer height

Cranfield University

Initial roughness - SLM



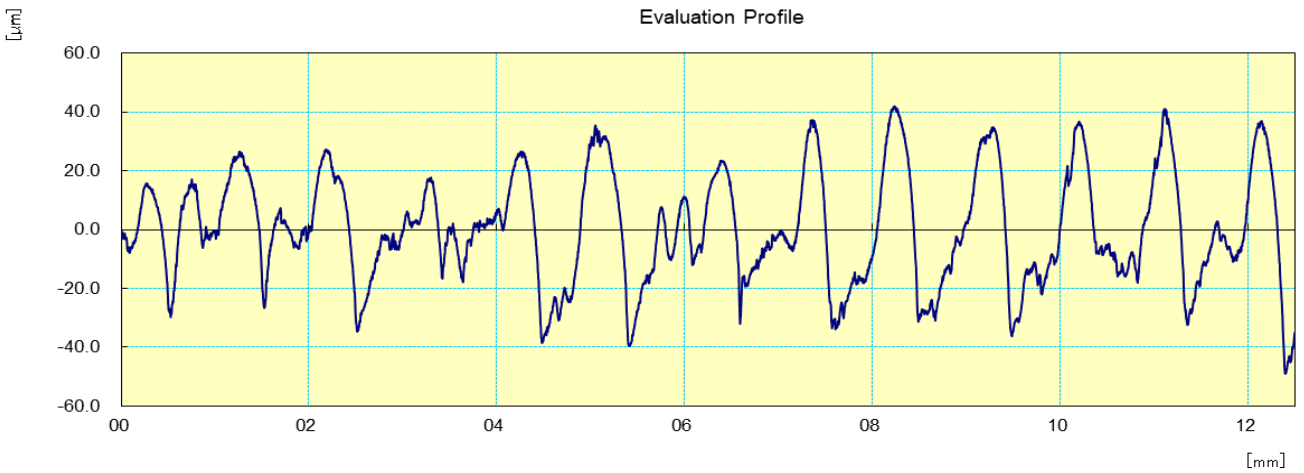


Scattering of initial sample roughness :

Ra values in the range of 8 to 18µm

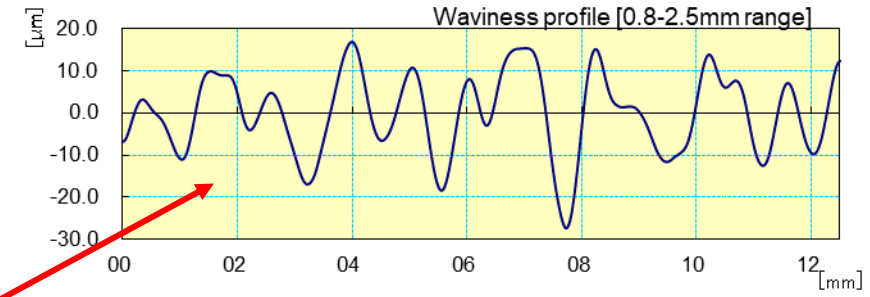
→ probably high SLM roughness due to unmolten particles (would require some sandblasting)

Initial roughness - LMD



- Ra values around 20µm
- Rz values around 100µm
- Rt values around 140µm

- Significant surface waviness in the range of 0.8 to 2.5mm, due to construction



Initial surface state - Summary

- The profile of the specimens is a mixture of a waviness and the actual roughness of the surface → must be uncoupled
- SLM shows a roughness that greatly varies between 8 and 18 µm
- LMD shows roughness values of the order of 20 µm. However the waviness is much higher fue to the layer thickness (~500 µm)

Surface post-processing of SLM by electropolishing

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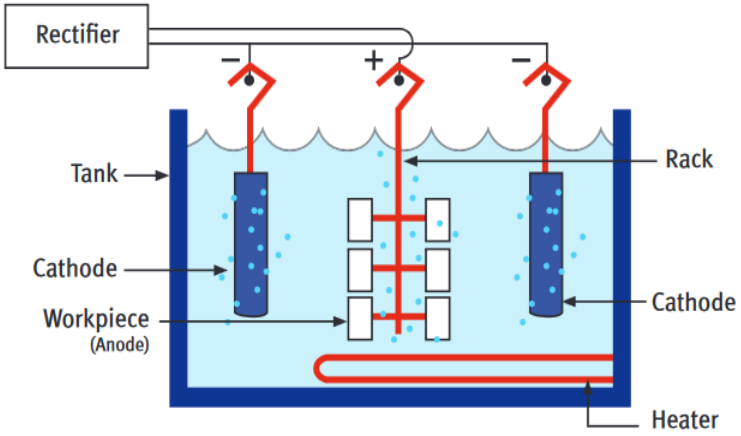
Electrochemical polishing (EP)

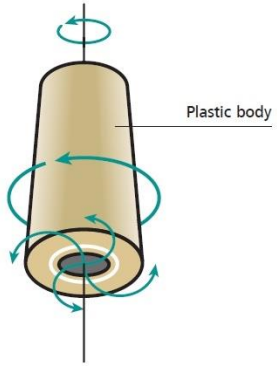
The technique

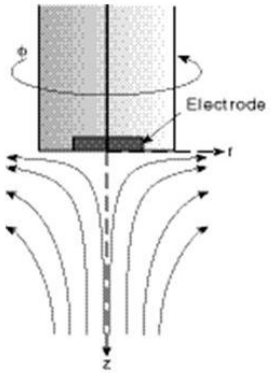


- Material removal achieved through a ‘controlled accelerated corrosion’ process
- Appropriate electrolytes (well formed diffusion layer) allow for faster dissolution of the peaks → surface smoothing

Electrochemical polishing

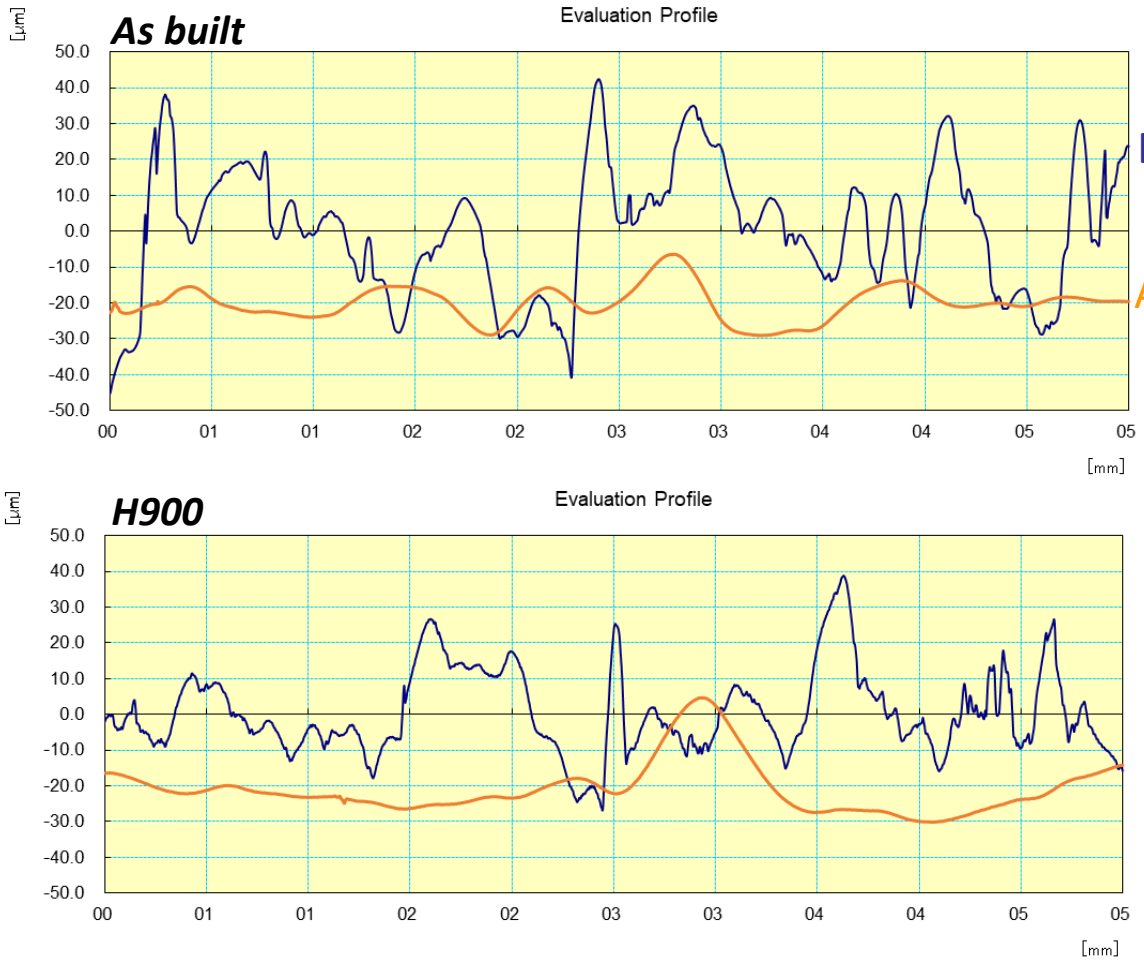
- Two polishing electrolytes were tested on the samples of INSIDE
  - Polishing conditions (Temperature, current density, time) were selected based on the technical data sheets and knowledge already present at CRM.
- Trials on discs carried out using a rotating disc electrode (RDE)
  - Allows for reproducible hydrodynamics
  - Allows for efficient heat transfer → controlled temperature
  - Small samples surface (electrode) → limited amount of electrolyte needed





Electrochemical polishing

Example of surface profiles on SLM parts for As-built and Heat-treated states



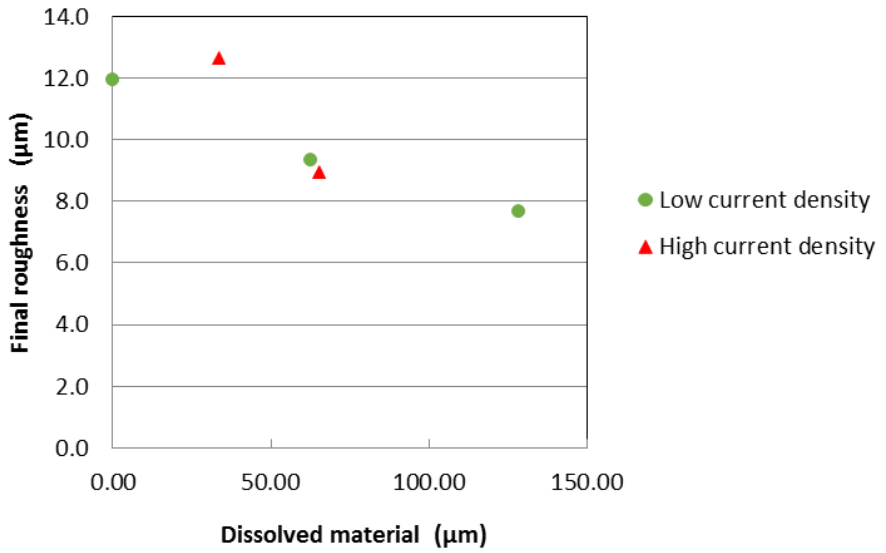
Before polishing

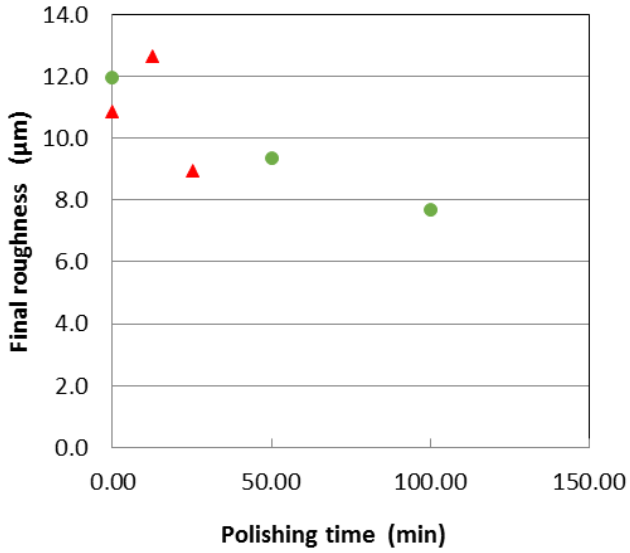
After 90min polishing

- Significant smoothing of the surface (peak removal)
- Some residual waviness which is much more difficult to remove by electropolishing
- Similar behaviour on as built and heat treated samples
- Final roughness Ra 4-6µm

Electrochemical polishing

Electrolyte 1 : mineral acid mix
Developed for stainless steel grades, works on some alloyed steel as well.

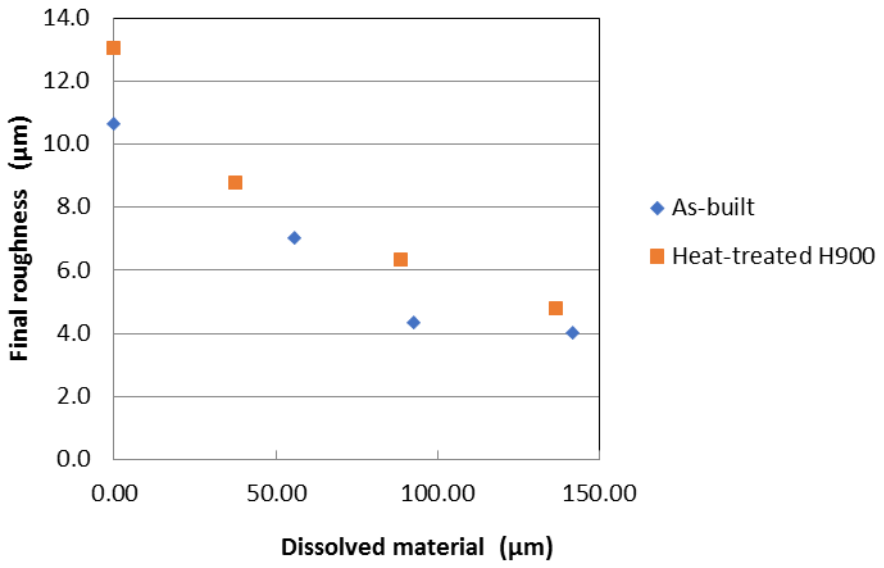


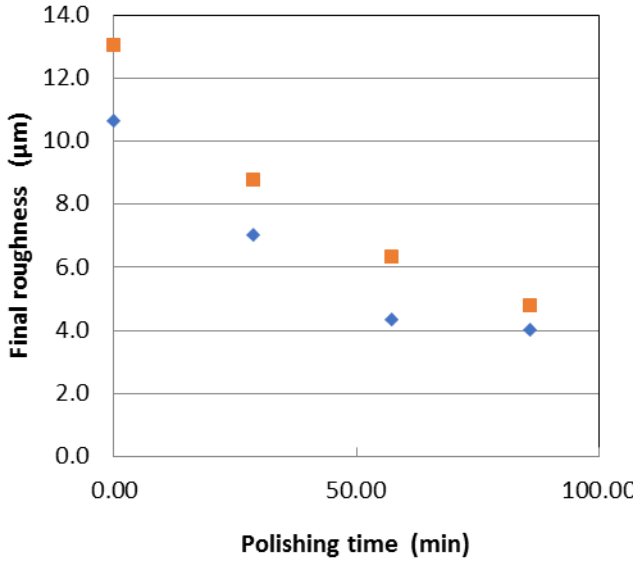


- Poor polishing performances at low and high current density (somewhat better at low c.d.)
- Similar effect as chemical polishing i.e. diffusion layer not well formed and less selective peak removal
- Minimum roughness achieved after removal of 140µm : 8µm Ra

Electrochemical polishing

Electrolyte 2 : organic-based electrolyte
Developed for tool steel.

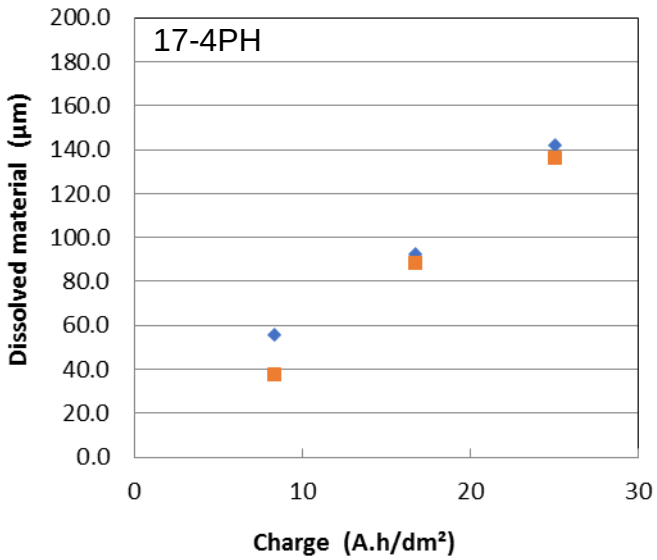




- Fairly good polishing performances under the selected polishing conditions
- No significant impact of H900 heat-treatment on polishing performances
- Minimum roughness achieved after removal of 140µm (90min) : 4µm Ra

Electrochemical polishing

Electrolyte 2 : organic-based electrolyte
Developed for tool steel.



Material removal rate : 1.6µm/min

◆ As built

■ Heat treated H900

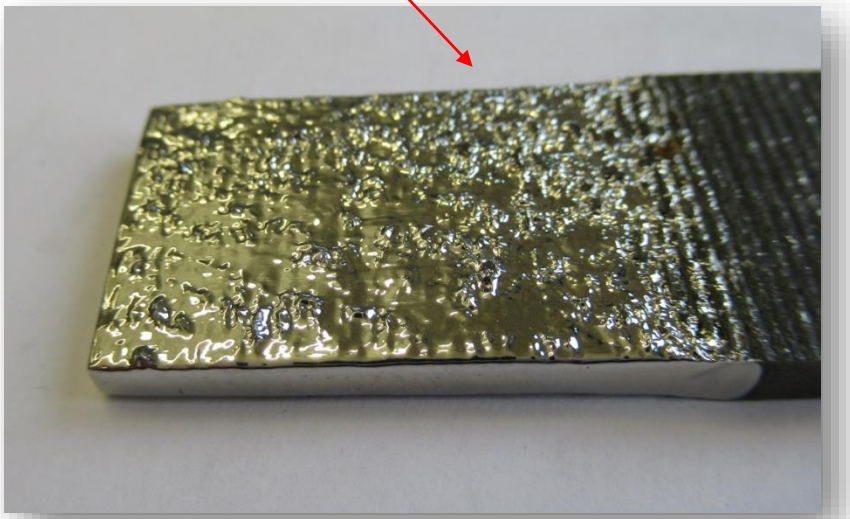
- Good control on (average) material removal rate for a given current density

Surface post-processing of LMD by electropolishing, chemical polishing & tribofinishing

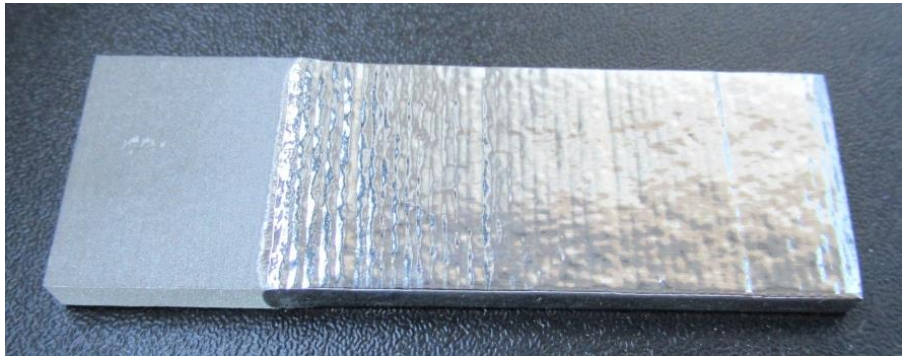
Electrochemical polishing - Sandblasting

- Sand-blasting is very important as a pre-treatment in order to remove the surface oxide & is very fast method with relatively low environmental impact
- The presence of the surface oxide film is very detrimental to the polishing homogeneity

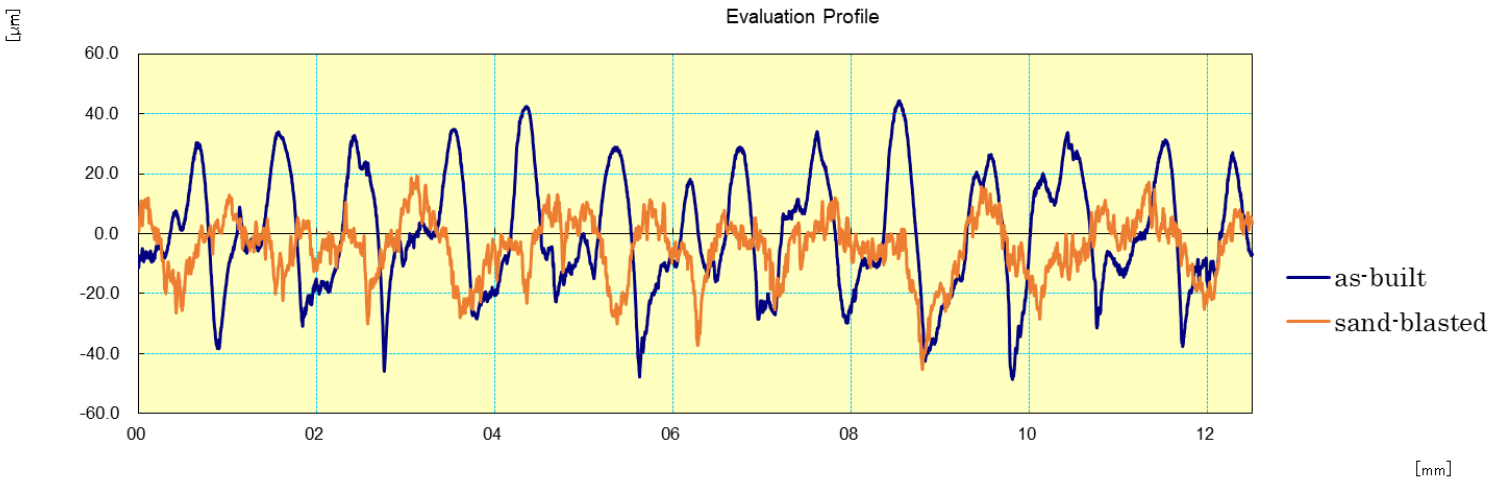
Non-sandblasted



Sandblasted



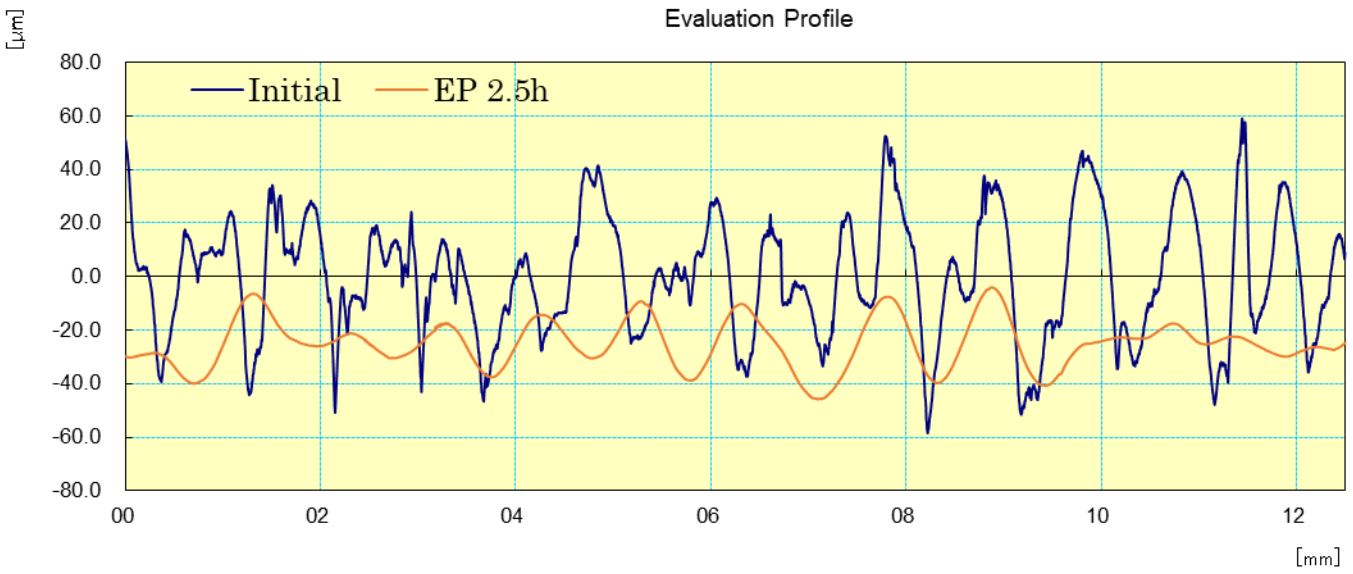
Electrochemical polishing - Sandblasting

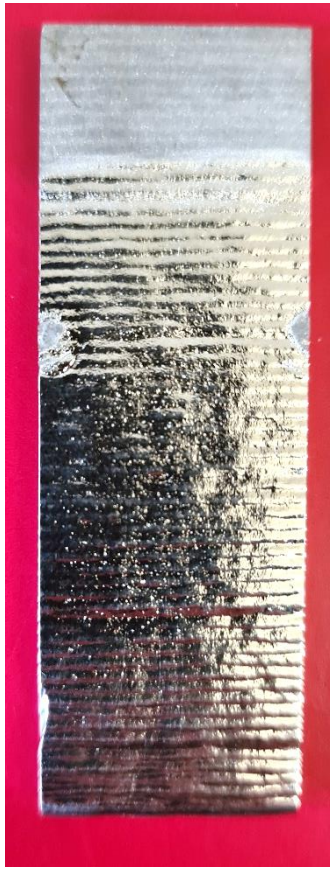


Sand-blasting :

- Effectively removes oxides and poorly melted particles from the surface
- Smoothens some large peaks (but obviously not the valleys!)
- Creates an additional low-wavelength roughness
- Ra decreases to 16µm

Electrochemical polishing

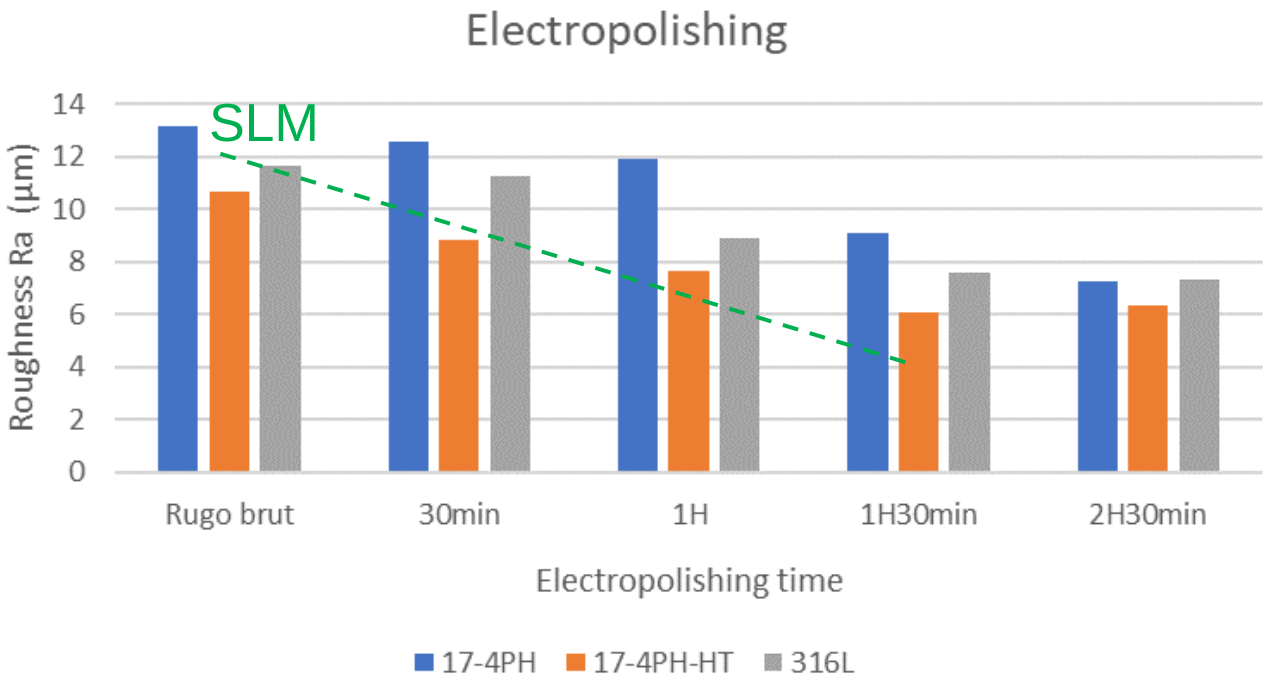




- Finishing conditions can be transferred from SLM to LMD parts
- LMD samples are characterized by a larger waviness, which is more difficult to remove
- Peaks are removed efficiently by EP (after initial sandblasting)
- Low-wavelength roughness is efficiently removed, which leads to a very bright and shiny surface finish
- After 1h of EP the Ra is already reduced to 14µm

Electrochemical polishing

Application to sand-blasted LMD samples

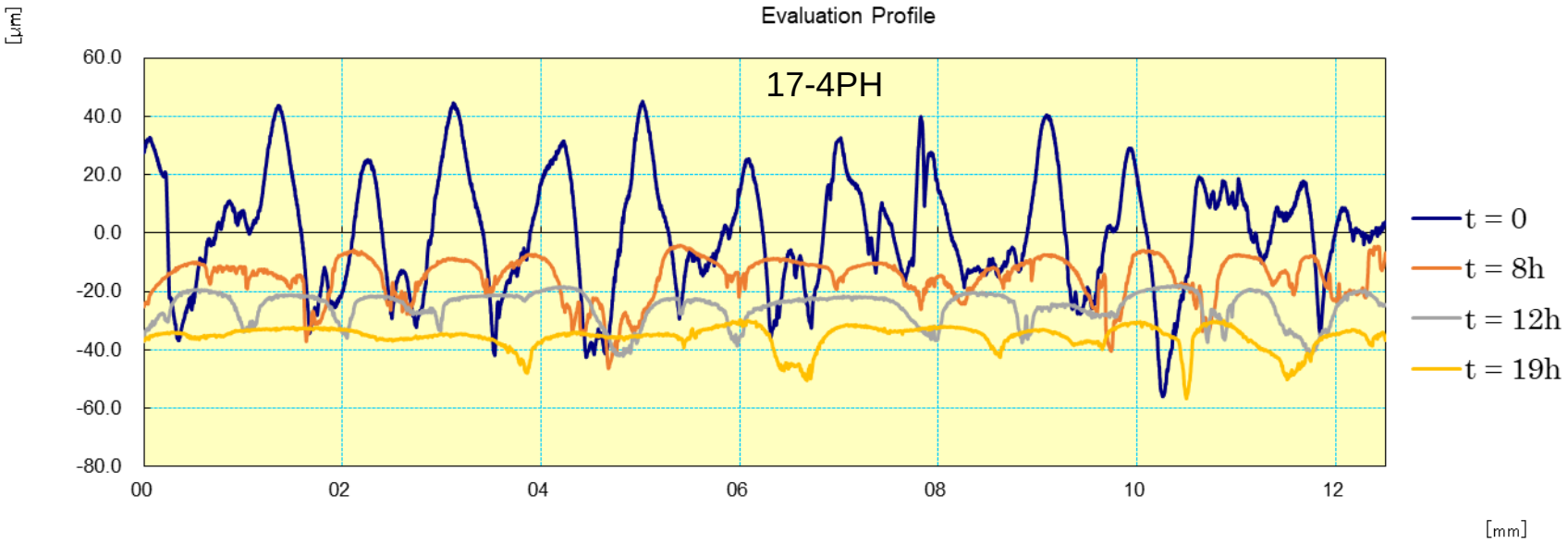


- After 2.5h of electropolishing : Ra decrease to 6-7 µm (vs ≈ 1h for SLM surface)
- After +/- 2h similar behavior on as built and heat-treated samples

Tribofinishing

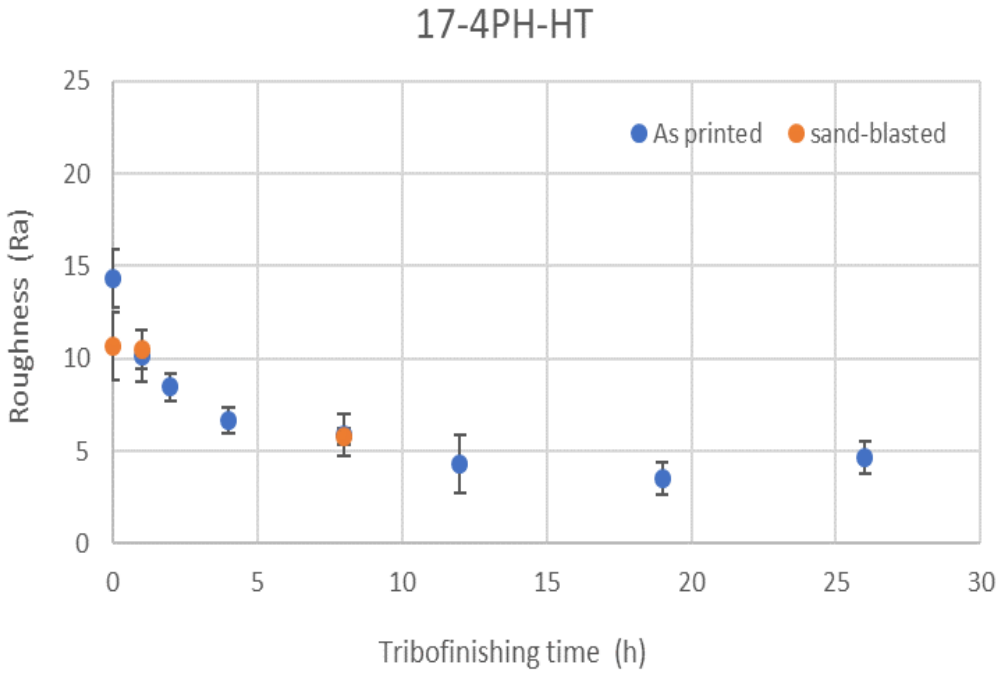
- Samples attached to the central shaft
- Ceramic abrasives flow along the rough surfaces
- Long treatment times (on hard metals) but very robust.

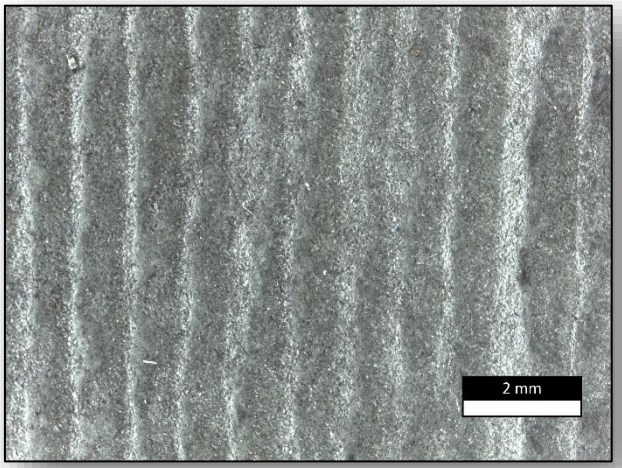
Tribofinishing



- Finishing conditions can be transferred from SLM to LMD parts but longer treatment times are needed
- Waviness is efficiently removed
- Dull-grey surface finish.

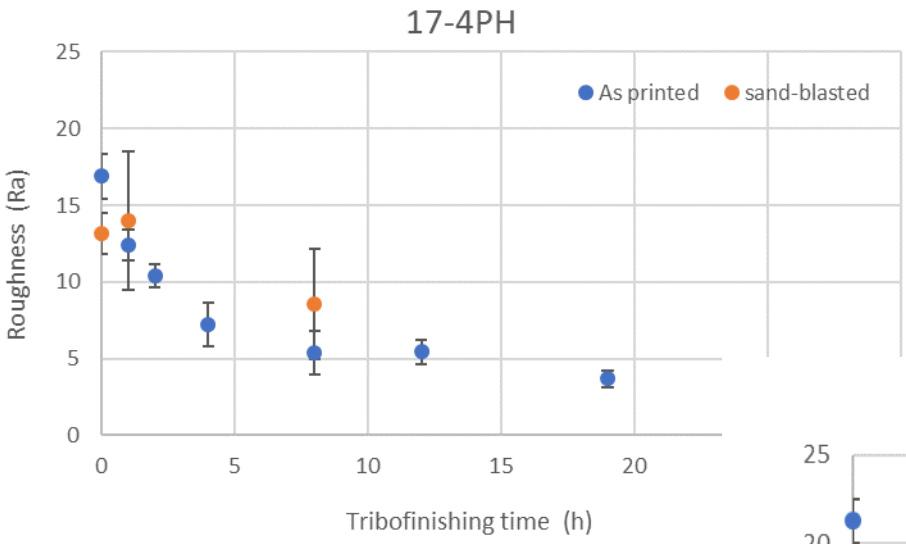
Tribofinishing





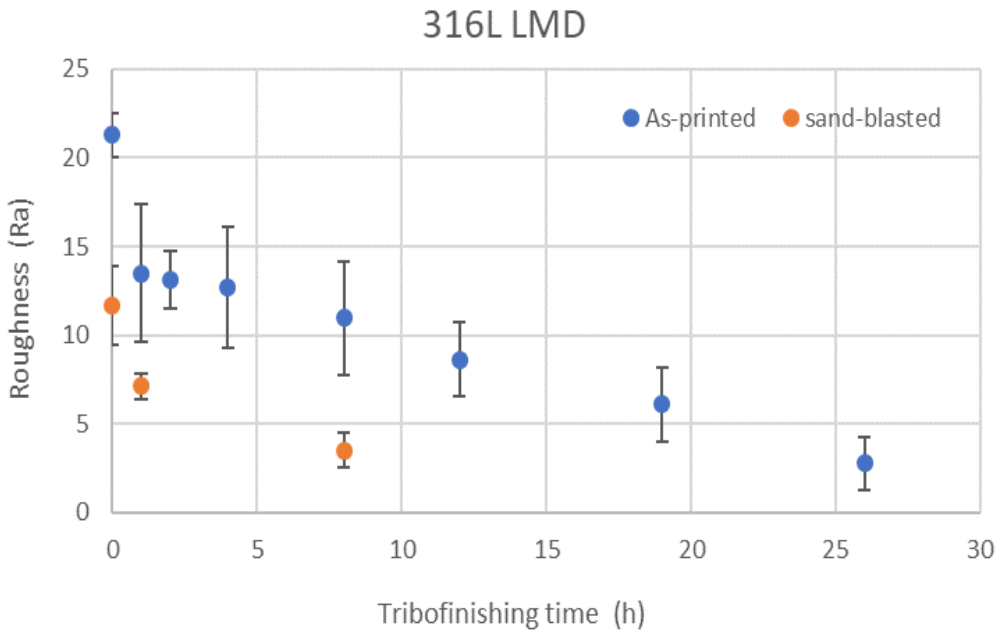
- Smoothing is a slow process
- Saturation is observed after ~20h.
- Roughness decreases down to ~3µm

Tribofinishing



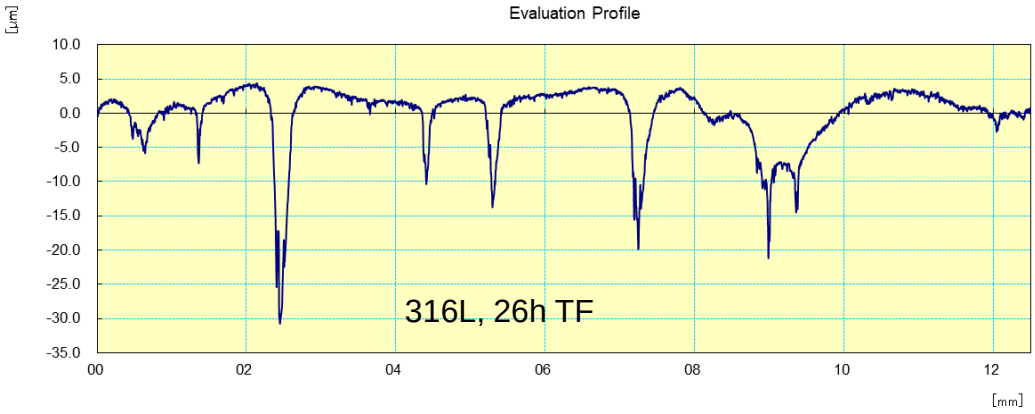
- On 316L, sand-blasting has a significant impact on the polishing kinetics

- On 17-4PH, sand-blasting does not influence the polishing kinetics



Tribofinishing - Summary

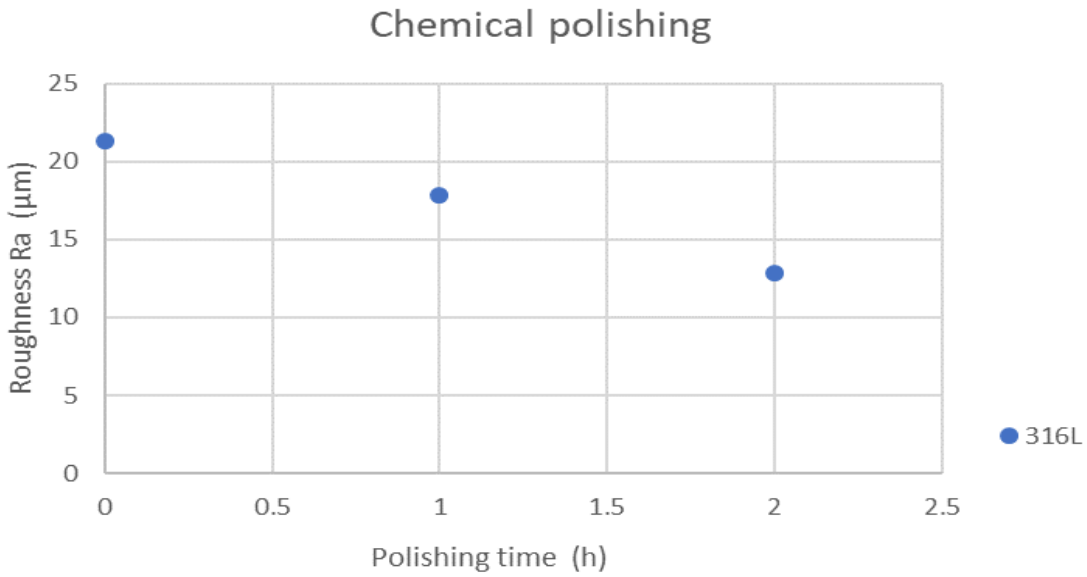
- Effective but slow (~0.1µm/min) → requires long treatment times (~20h)
- Removes peaks preferentially (minimum material waste)
- Limitations :
  - Rounding of edges
  - Some areas might not be accessible to abrasives
  - Valleys are poorly/not treated

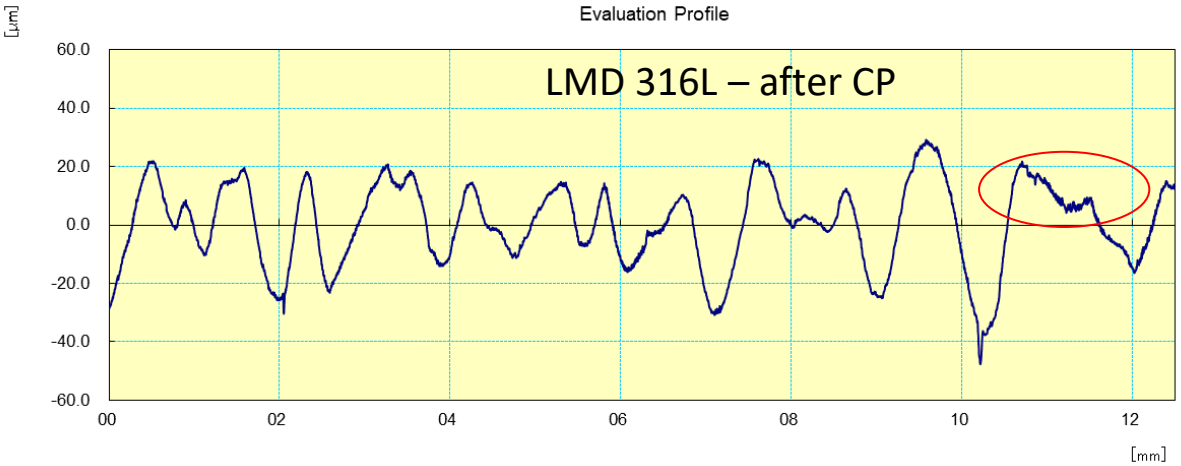


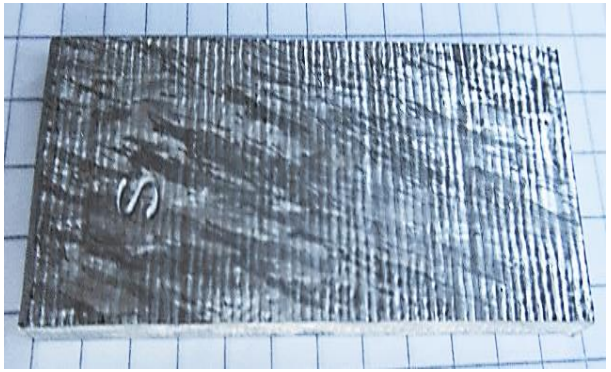
Chemical polishing – Not efficient for LMD

LMD samples

- Electrolyte validated for 316L steel
- Limited surface smoothing is observed
- Not very efficient on LMD samples
- on 17-4PH also not efficient







LMD post-processing - Summary

- Electrochemical polishing:
  - Similar behaviour for 17-4PH and 316L independently of the heat treatment
  - Impossible to remove waviness.
  - Need for some sandblasting
- Tribofinishing:
  - Tribofinishing effectively removes the waviness after quite long (automated) treatments up to 20h
  - Removes peaks preferentially
- Chemical polishing: not well adapted

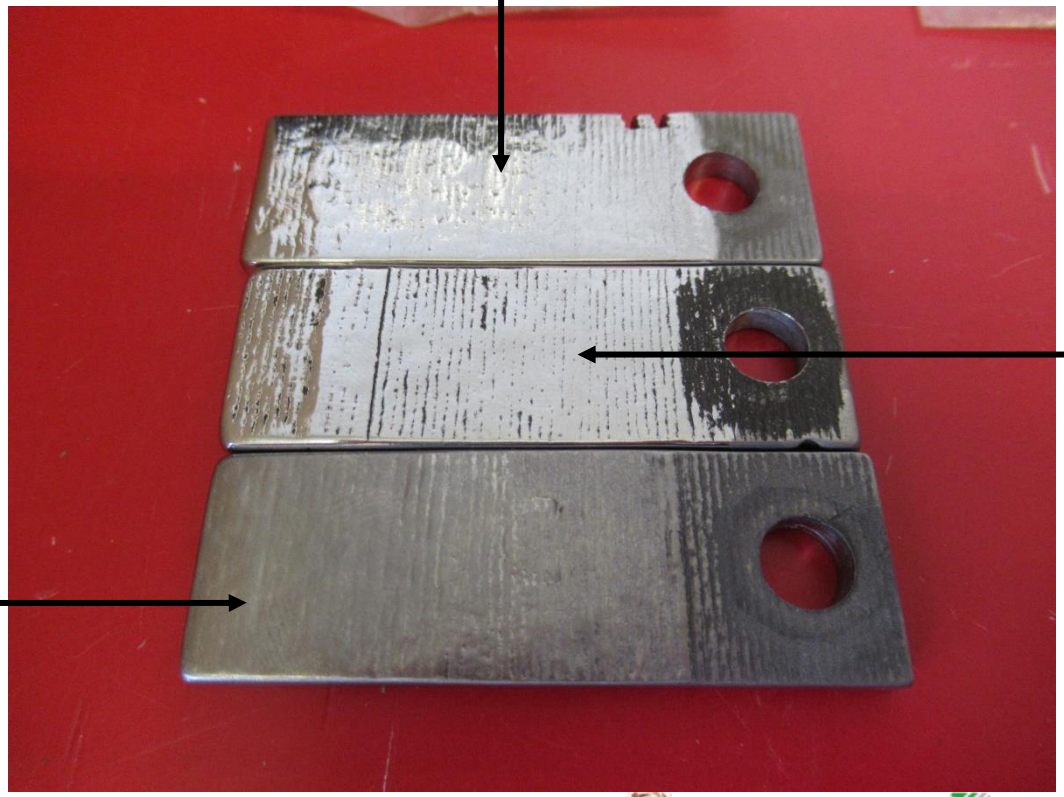
Surface post-processing of LMD – Combination of techniques

Combination of finishing techniques

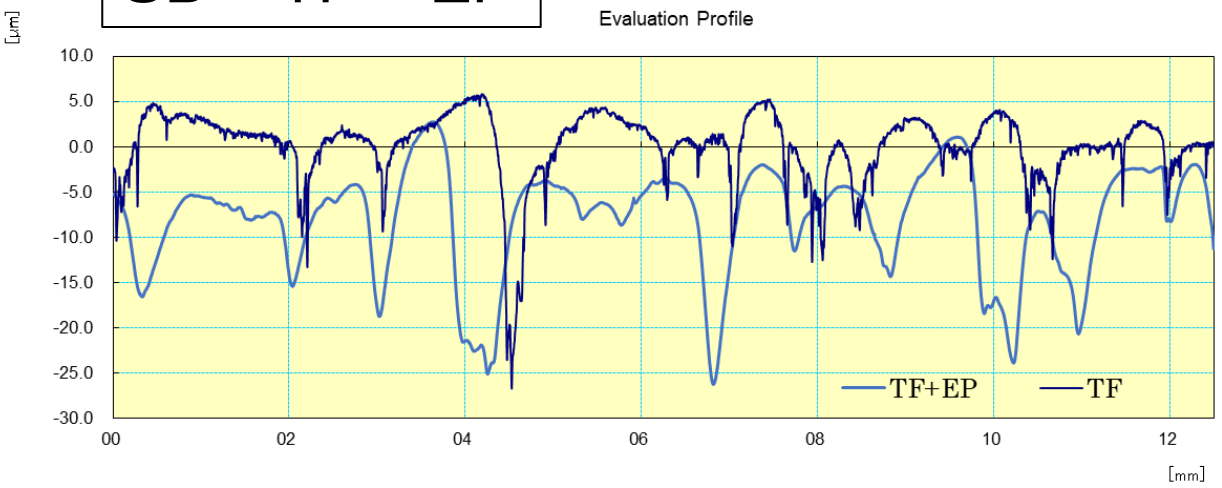
Sandblasting + Electropolishing + Tribofinishing

Sandblasting + Tribofinishing + Electropolishing +

Tribofinishing + Electropolishing



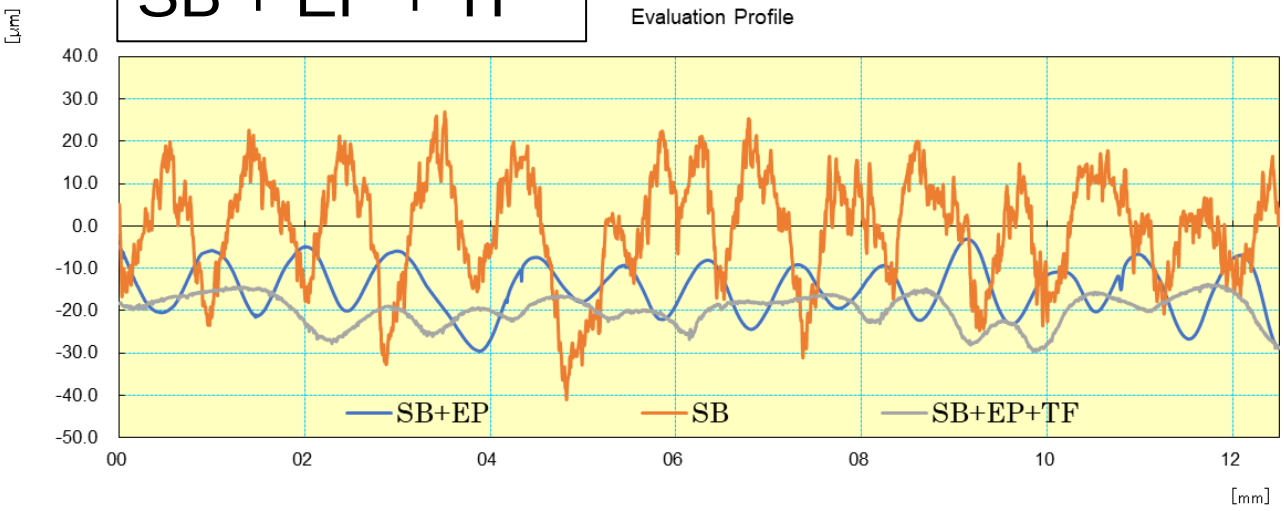
SB + TF + EP



8h Tribofinishing (TF)
30min Electropolishing (EP)

Ra : 4.91 µm

SB + EP + TF



3h Electropolishing (EP)
2h Tribofinishing (TF)

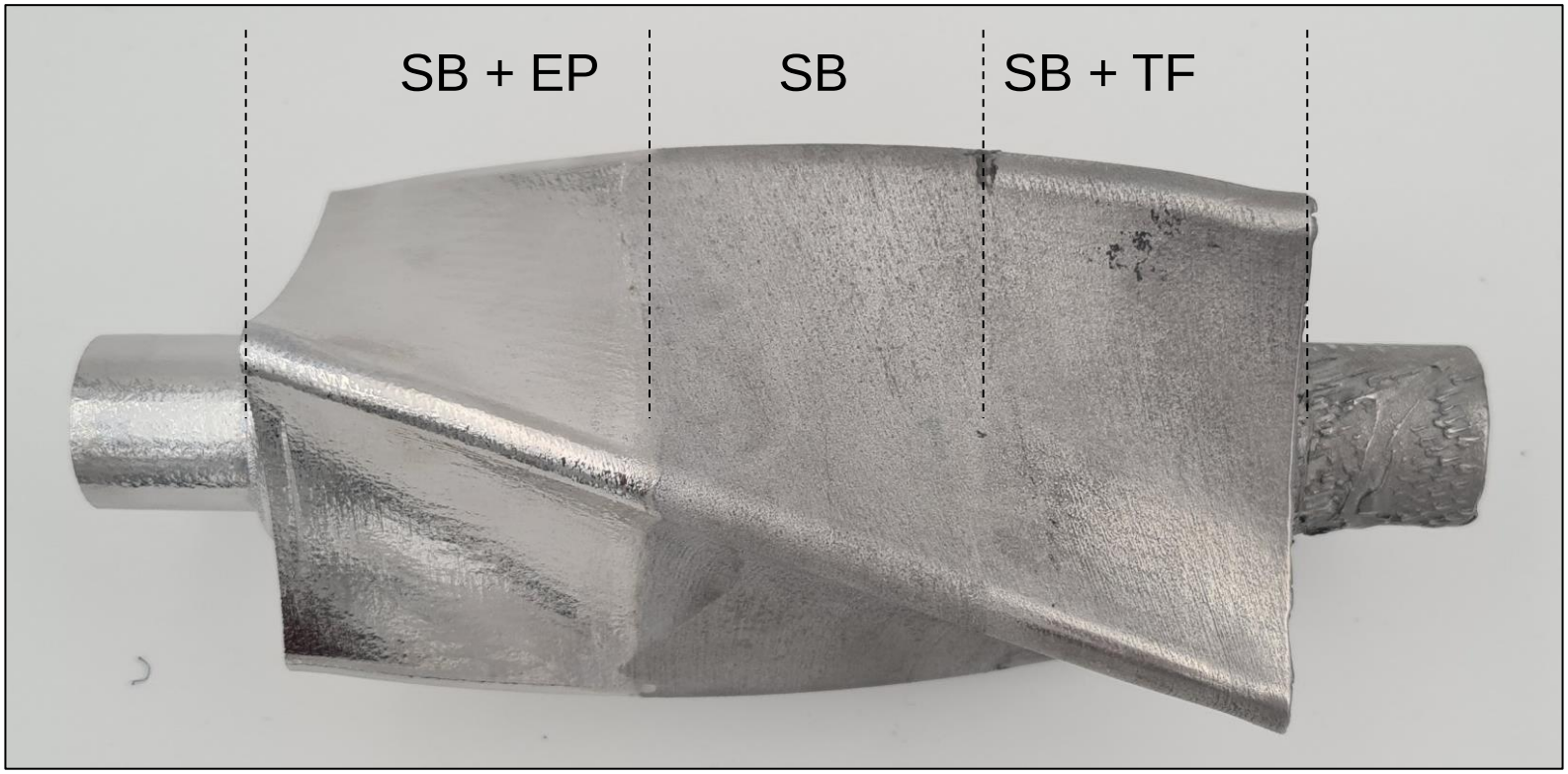
Ra : 4.01 µm

LMD post-processing combination - Summary

- Sand blasting as a first step provides for homogeneous action of the subsequent electropolishing treatment (oxides etc. removed)
- EP after TF improves drastically the visual quality and cleanliness
- EP before TF allows decreasing the duration of the finishing process

Polishing of rotor demonstrators

Polishing of demonstrators – SLM rotor

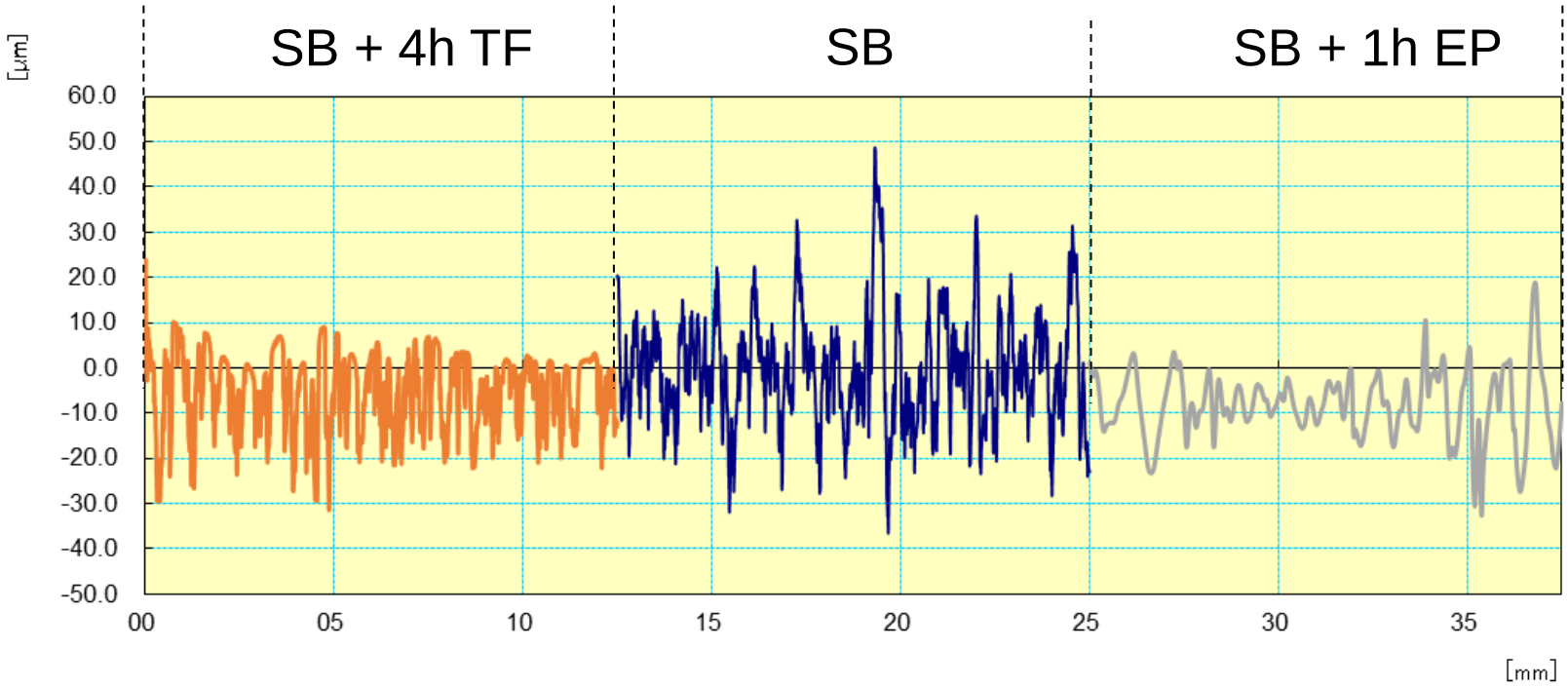


- The whole part was first sand-blasted.
- Tribofinishing and electropolishing were compared on both ends of the rotor.

Polishing of demonstrators – SLM rotor

- Silicone masks were applied on the parts in order to preserve selected areas during tribofinishing and electropolishing

Polishing of demonstrators – SLM rotor



- After 4h of tribofinishing, most surface peaks are removed. The surface feels soft (to the finger). Valleys are untouched. The surface is dull.
- 1h of electropolishing results in a wavy surface with no residual nano-roughness. The surface is bright.

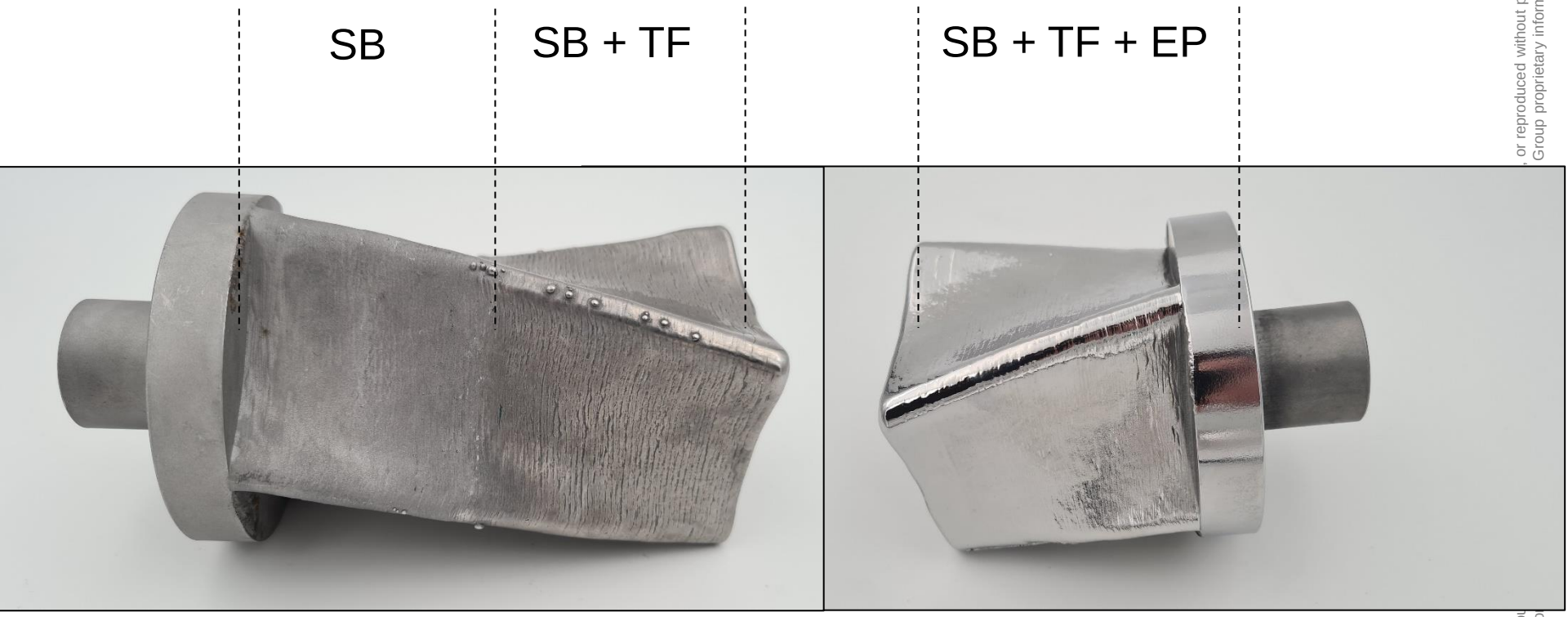
Polishing of demonstrators - SLM rotor

	Ra (µm)	Rsk
SB + TF (4h)	8.4 ± 1.7	-0.4 ± 0.2
SB	12.5 ± 4.1	0.6 ± 0.4
SB + EP (1h)	4.0 ± 1.2	0.0 ± 0.1

- After tribofinishing more valleys are left (i.e. preferential peak removal) → $Rsk < 0$
- After electropolishing valleys & peaks are similarly represented → $Rsk \approx 0$

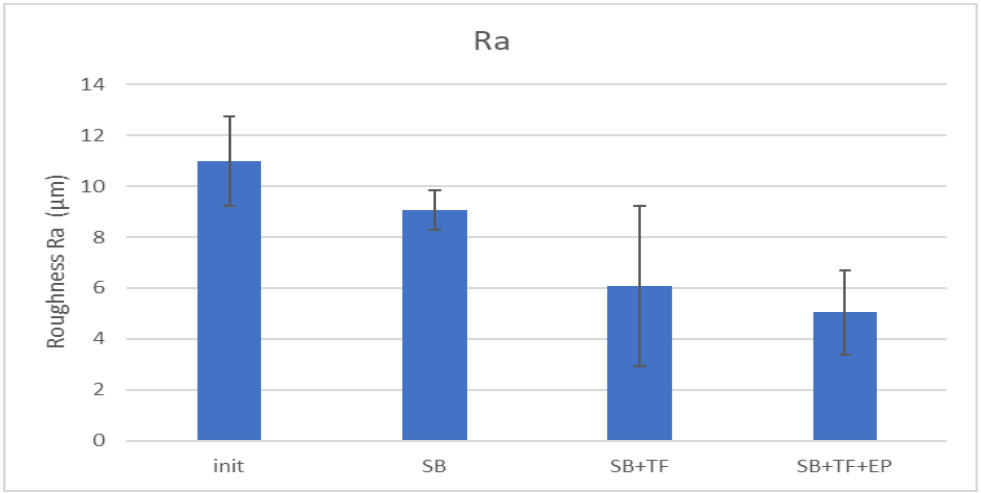
Polishing of demonstrators – LMD rotor

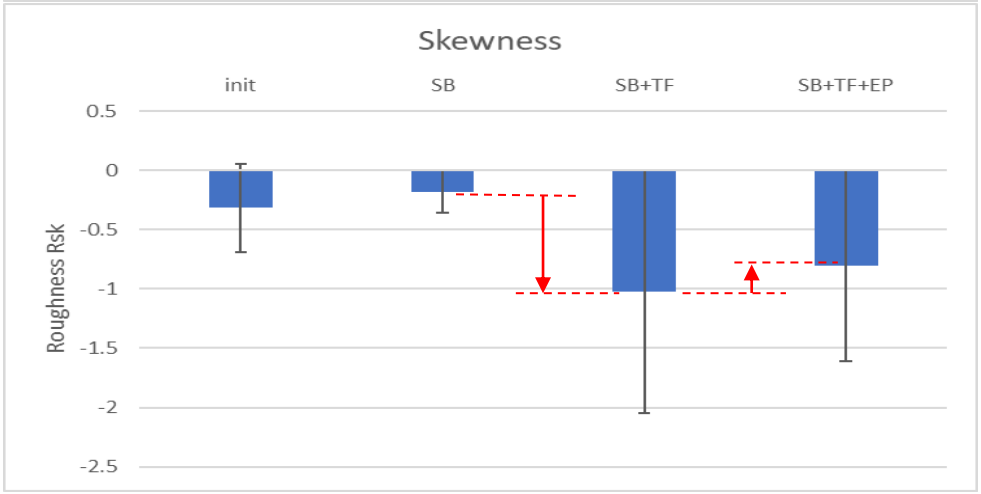
Polishing of demonstrators – LMD rotor



- Cumulative surface treatments were also applied on the LMD rotor (progressive SB-TF-EP)
- Only TF +/- 31h, EP +1h

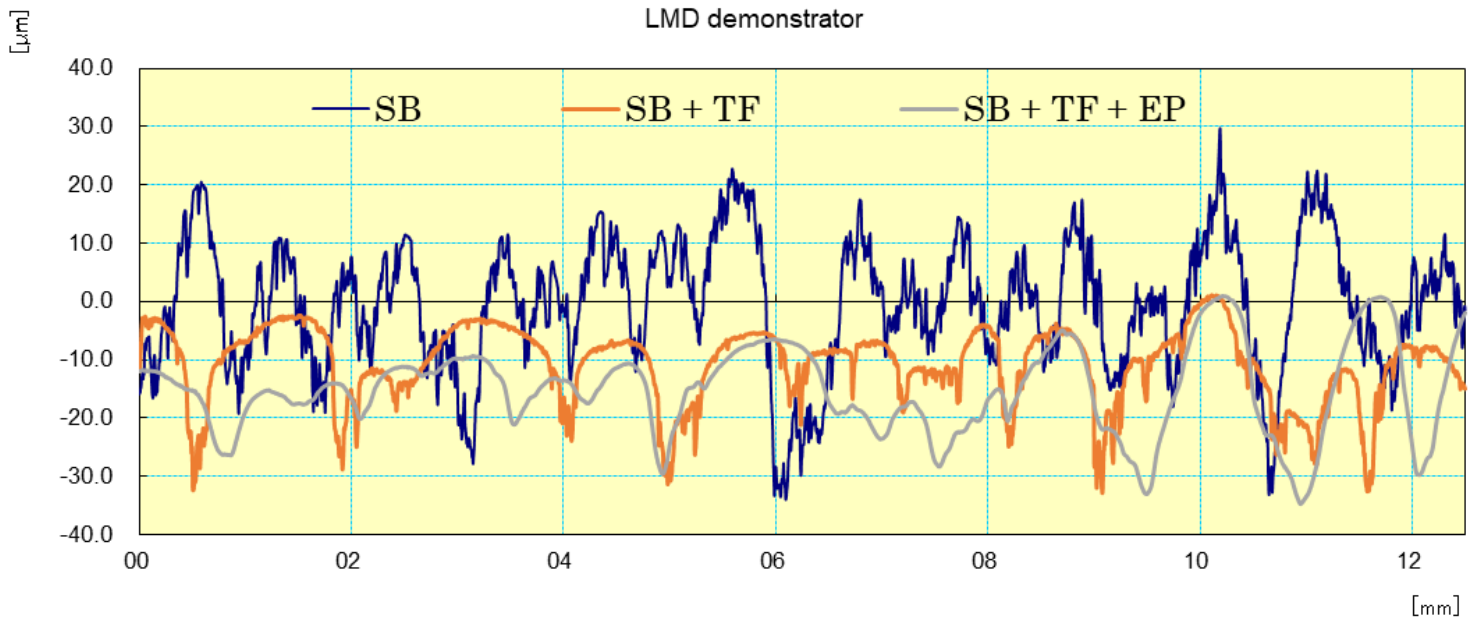
Polishing of demonstrators - LMD rotor





- Standard deviation calculated on 4 samples (i.e. black bars i/t graphs)
- Change in Rsk indicates removal of peaks vs valleys (i.e. red arrows)

Polishing of demonstrators – LMD rotor



- Surface treatments can be cumulated in a synergetic way to achieve a good surface finish on LMD parts
  - Sand-blasting efficiently cleans the surface and removes thick oxides
  - Tribofinishing eliminates long-wavelength roughness
  - Electropolishing removes the nano-roughness and brightens the surface
- In our case, a longer tribofinishing time should have been selected

Post-processng of demonstrators - Summary

- Combining surface treatments provides better results
- Sandblasting + Electropolishing provides the best results for SLM
- A combination of Sandblasting + Tribofinishing + Electropolishing provides the best results for LMD