4th International Conference on Laser Peening and Related Phenomena

Assessment of laser peening induced effects on Ti6Al4V by non-destructive measurements

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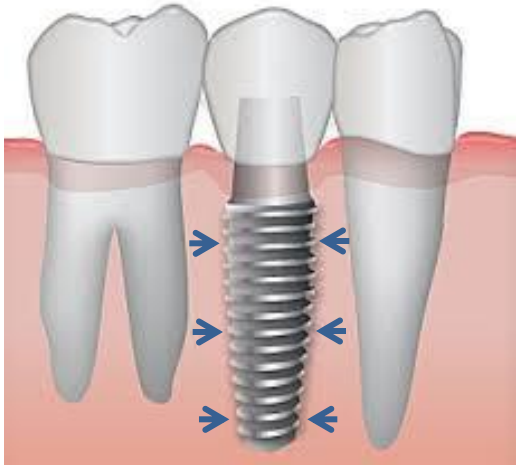
Centro Investigación Biomédica en Red
Bioingeniería, Biomateriales y Nanomedicina

Orthopedic and dental implant applications

Material: Ti-6Al-4V

One of the most appropriate biomaterials for **load-bearing implants:**

- Good mechanical properties
- High corrosion resistance
- Good biocompatibility (Bioinert)



Biological response is regulated by the material / tissue interface

Orthopedic and dental implant applications

SURFACE MODIFICATIONS BASED ON SEVERE PLASTIC DEFORMATION

GRIT BLASTING (GB)

Al_2O_3 / ZrO_2

R_a { GB-Al_2O_3 ≈ 5.1 µm
GB-ZrO_2 ≈ 1.0 µm

Beneficial effects

- Increases surface roughness
- Increases **compressive residual stress**

↓

- **Increases fatigue resistance**

Orthopedic and dental implant applications

SURFACE MODIFICATIONS BASED ON SEVERE PLASTIC DEFORMATION

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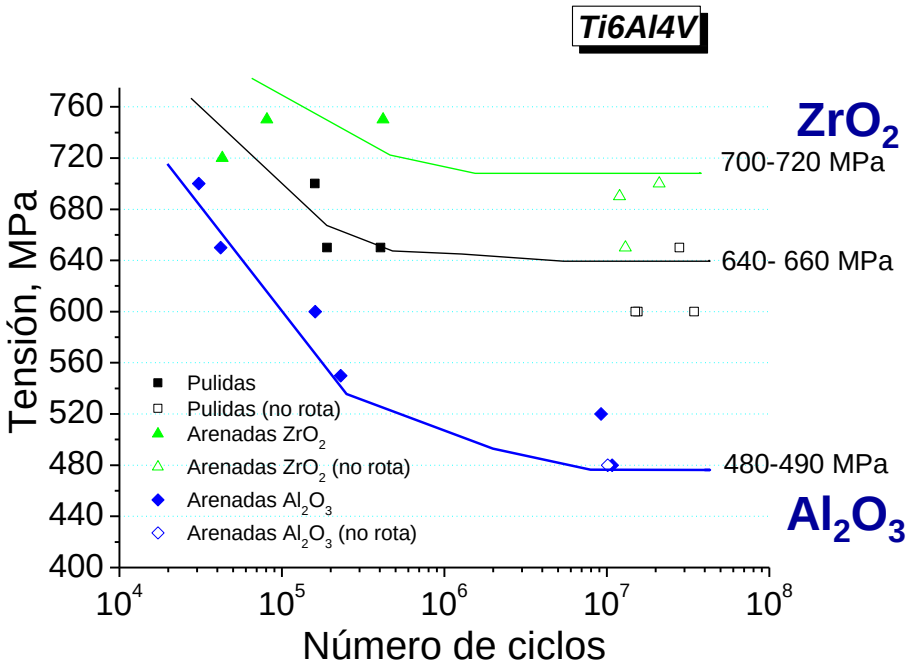

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Beneficial effects

- Increases surface roughness
- Increases **compressive residual stress**

↓

- **Increases fatigue resistance**

Detrimental effects

- Surface contamination
- **Stress concentrators**

↓

- **Decreases fatigue resistance**

Problem solving approach

LASER PEENING WITHOUT COATING

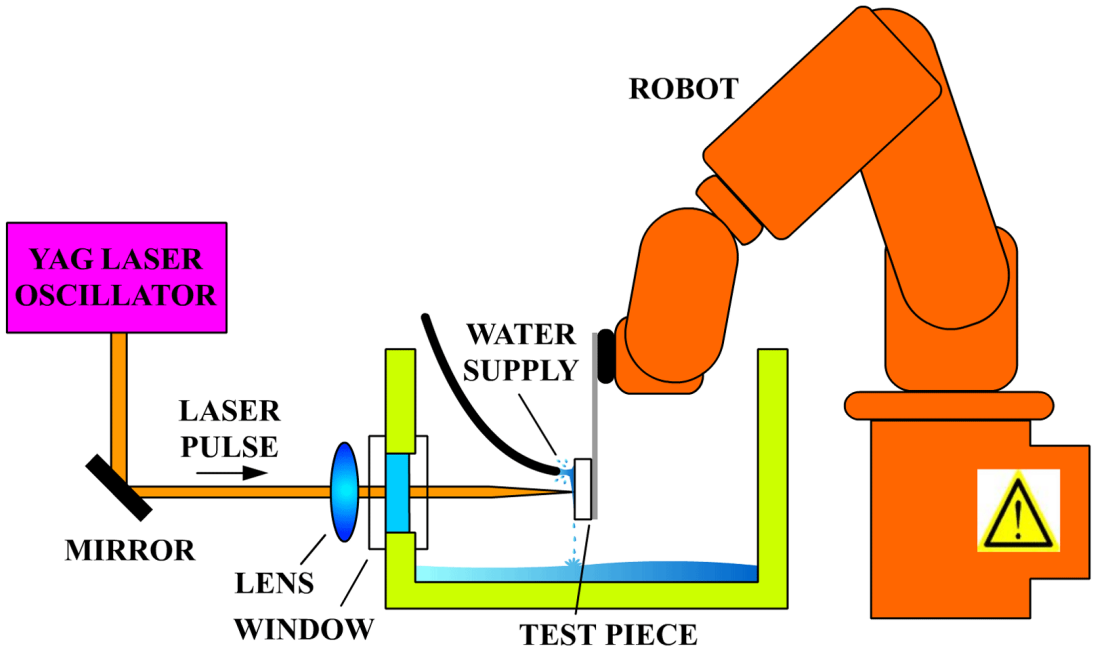
Alternative to achieve **compressive residual stress** at a **depth of 1 mm**, **avoiding stress concentrators**:

- **Delaying** the **nucleation** and **propagation** of **cracks**.

- **Improving** the **fatigue** resistance.

Q-switched Nd-YAG Laser irradiation:

- E = 2,8 J / pulse
- τ = 9 ns
- Ø pulse = 1,5 mm
- EOD = 5000 cm^{-2}
- Confining medium: water
- No sacrificial coating



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Evaluating LP induced effects

RELEVANT ITEMS

SURFACE

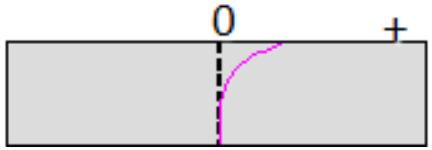
Topography and surface roughness

Strong effect on biological response

SUBSURFACE

compressive residual stress

cold work (hardening, texture)



grain refinement / precipitates

Strong effect on mechanical behaviour

Evaluating LP induced effects

RELEVANT ITEMS

SURFACE

Topography and surface roughness

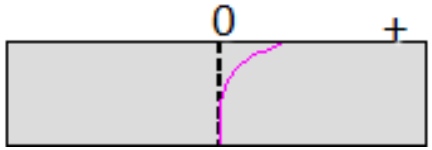
- Scanning Electron Microscopy (SEM)
- X-Ray Diffraction (XRD)
- Mechanical profilometry

SUBSURFACE

compressive residual stress

- X-Ray Diffraction (XRD)
- Syncrotron X-Ray Diffraction
- Neutron Diffraction
- Hole Drilling (HD)

cold work (hardening, texture)



- Optical Microscopy (OM)
- Scanning Electron Microscopy (SEM)
- Transmission Electron Microscopy (TEM)
- Electron Backscatter Diffraction (EBSD)

grain refinement / precipitates

- Vickers Microhardness (HV), …

Evaluating LP induced effects

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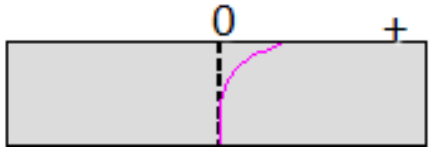


grain refinement / precipitates

Our proposal:

THERMOELECTRIC POWER MEASUREMENTS

INSTITUTO DE INVESTIGACIONES METALÚRGICAS
UNIVERSIDAD MICHOACANA, MÉXICO

Thermoelectric power measurements (TEP)

METHODS

SEEBECK PRINCIPLE: Thermoelectric property that causes the conversion of a **temperature difference** into **electricity**.

Hot tip method

↓

Mainly sensitive to:

Solute content and lattice defects

Magnetic method

↓

Mainly sensitive to:

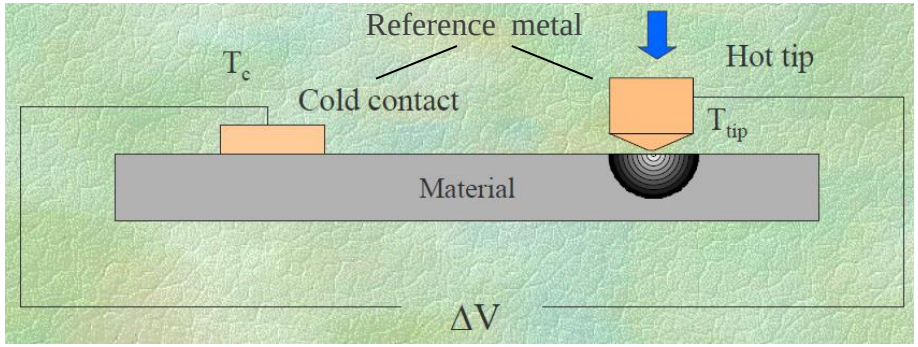
Residual stress

Insensitive to the sample **geometry** and the **surface roughness**

Thermoelectric power measurements (TEP)

METHODS

Hot tip method



Measuring time 1 s

Accuracy ± 0.5%

Resolution 1 nV/K

• When a **closed loop** is made of two metals with a **temperature difference** at the joints between them, a **potential difference (ΔV)** is induced **(Seebeck effect).**

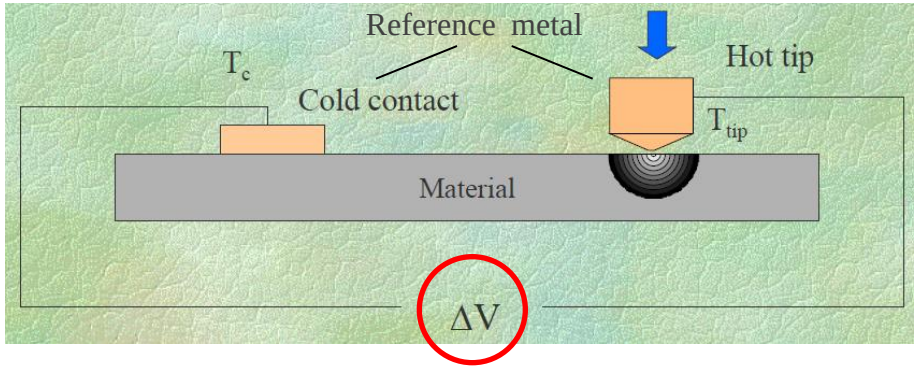
• The **thermoelectric power (ΔS)** of the sample (S_M) relative to the reference metal (S_{tip}) is given by the relation:

$$\Delta S = S_M - S_{tip} = \Delta V / \Delta T \qquad (nV/K)$$

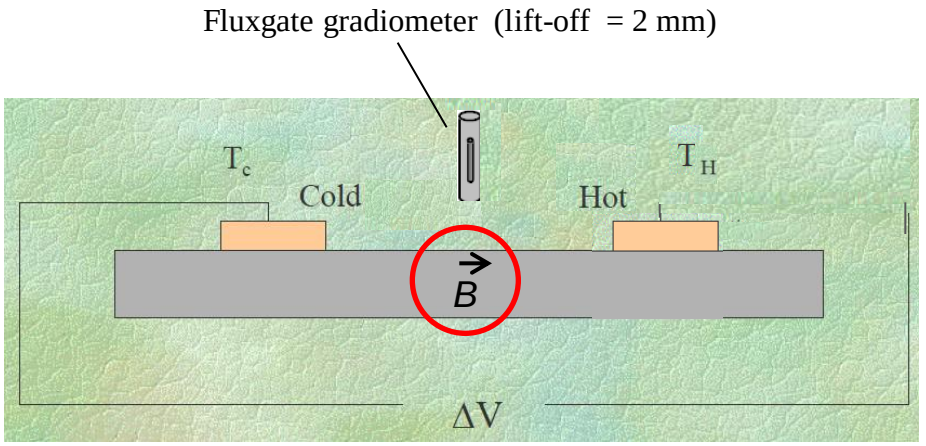
Thermoelectric power measurements (TEP)

METHODS

Hot tip method



Magnetic method



Thermoelectric power measurements (TEP)

STRATEGY FOR EVALUATING THE POTENTIAL OF THE TEP MEASUREMENTS

Combination of LP with two standard heat treatments

1- Partial residual stress relief (595ºC / 1h)

2- Total residual stress relief (710ºC / 2h)

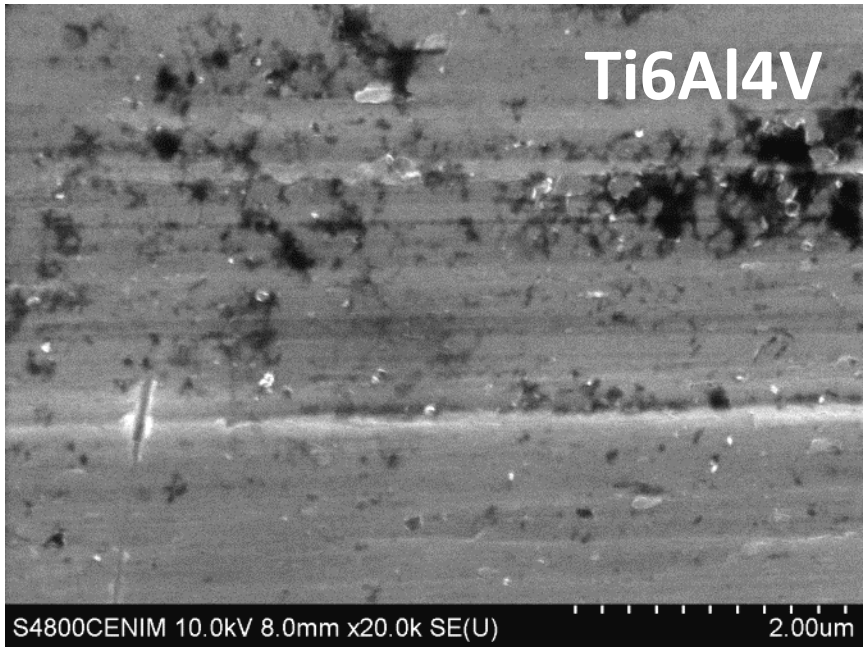
↓

Five different conditions

Surface Evaluation

TOPOGRAPHY

As machined



Surface Evaluation

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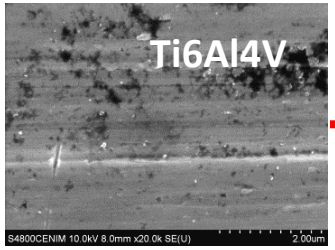
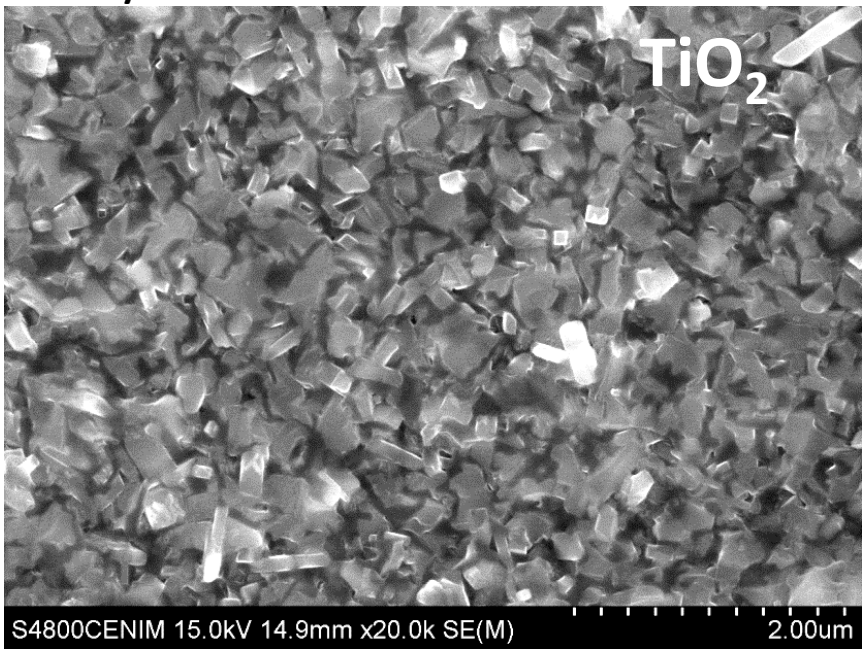


710ºC / 2h



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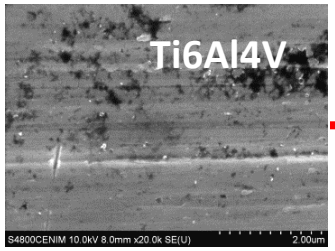
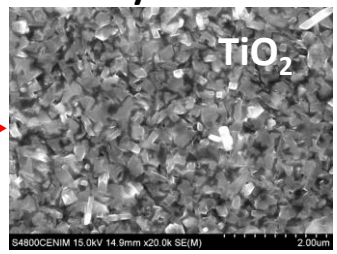
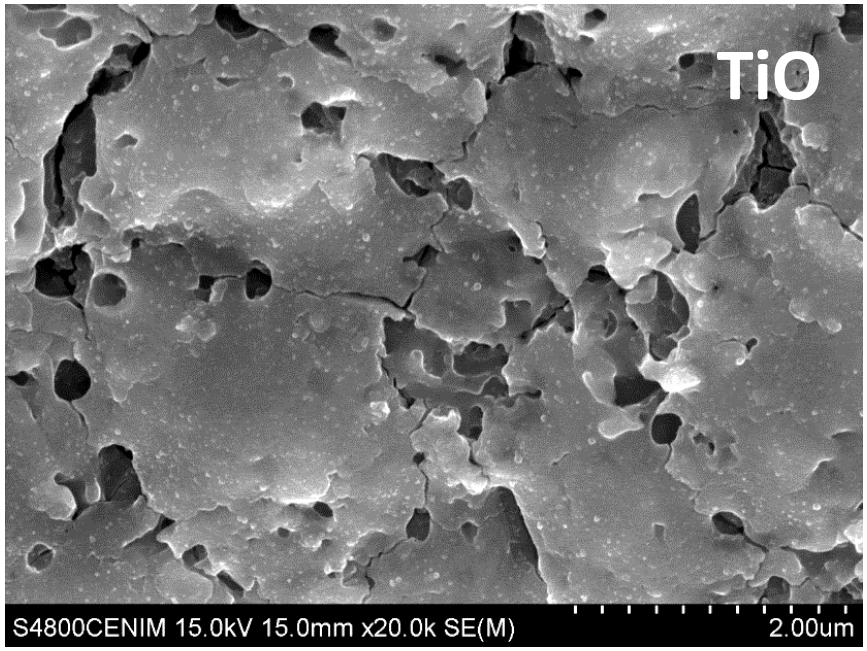


710ºC / 2h



Laser Peened



Surface Evaluation

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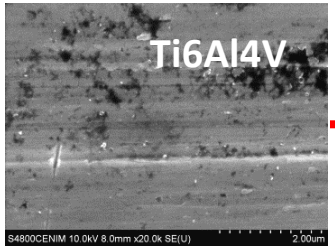
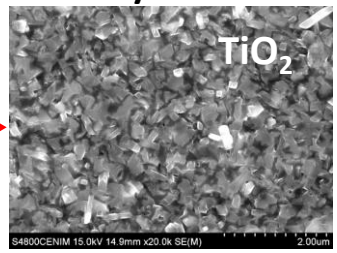
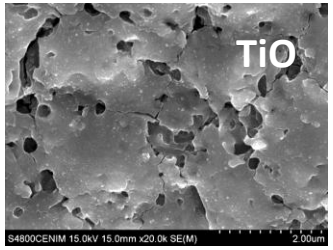


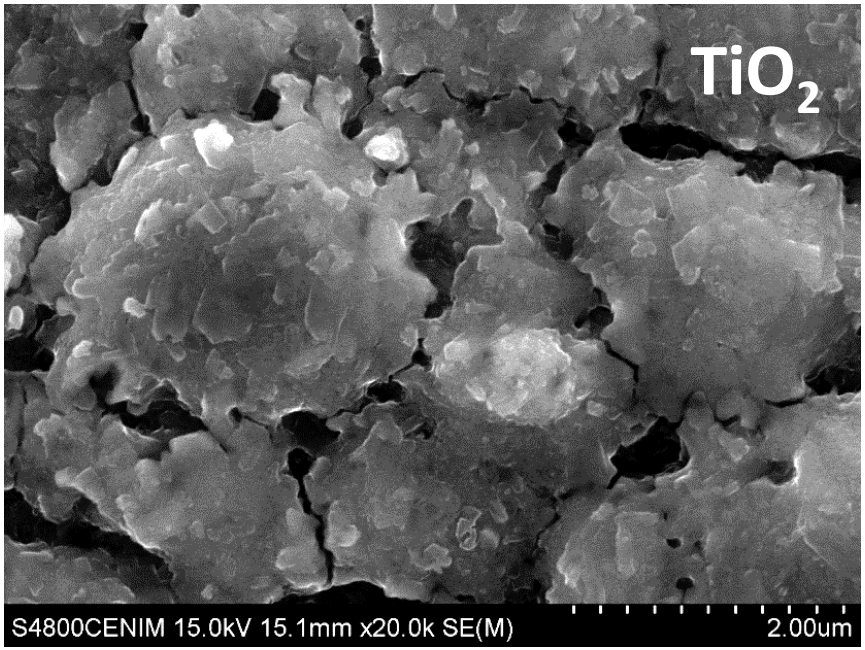
710ºC / 2h



Laser Peened



595ºC /1h



Surface Evaluation

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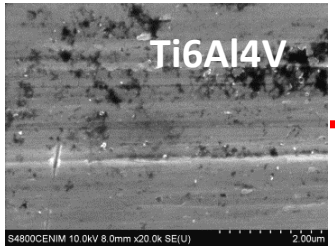
As machined



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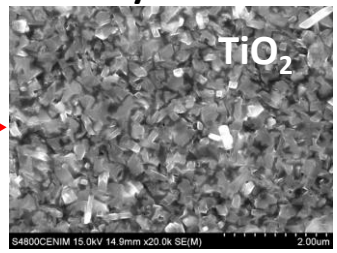
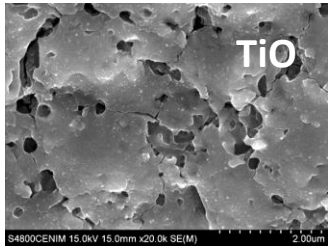


Laser Peened



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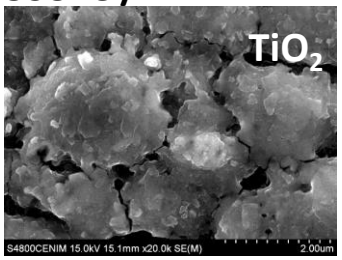
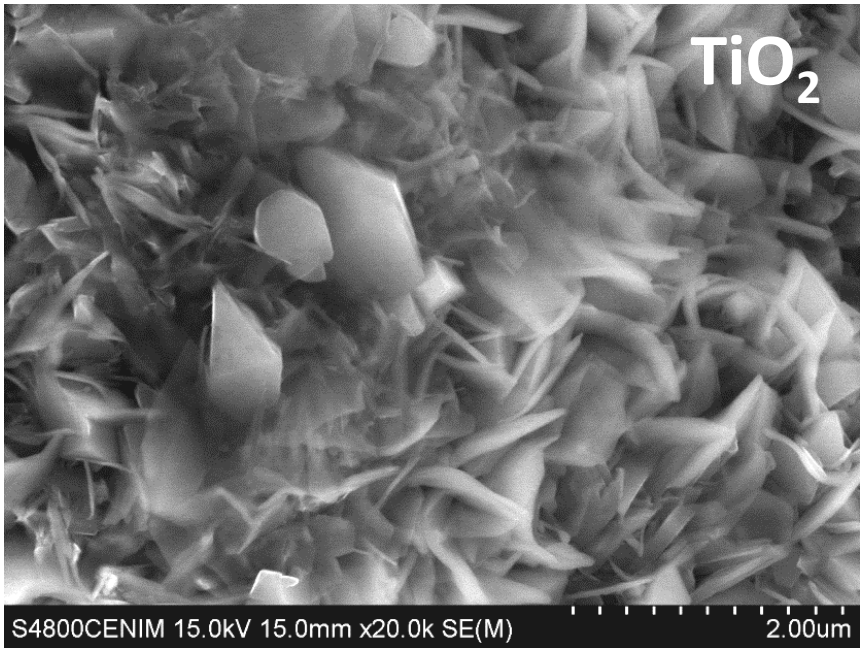


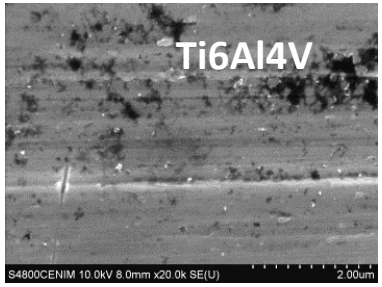
710ºC /2h



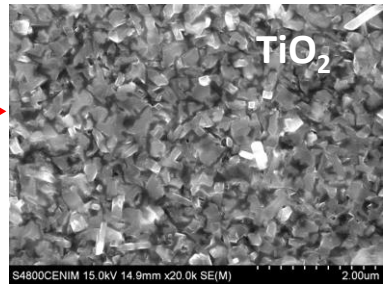
Surface Evaluation

ROUGHNESS

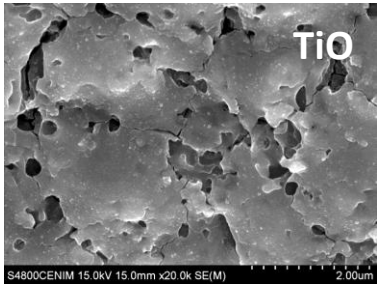
As machined



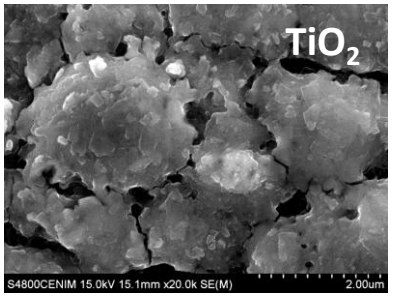
710ºC / 2h



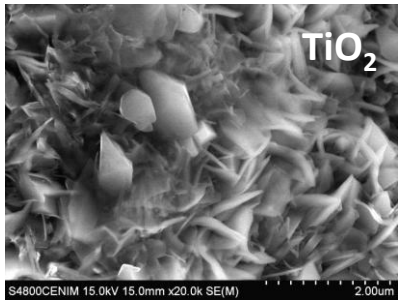
Laser Peened



595ºC /1h



710ºC /2h



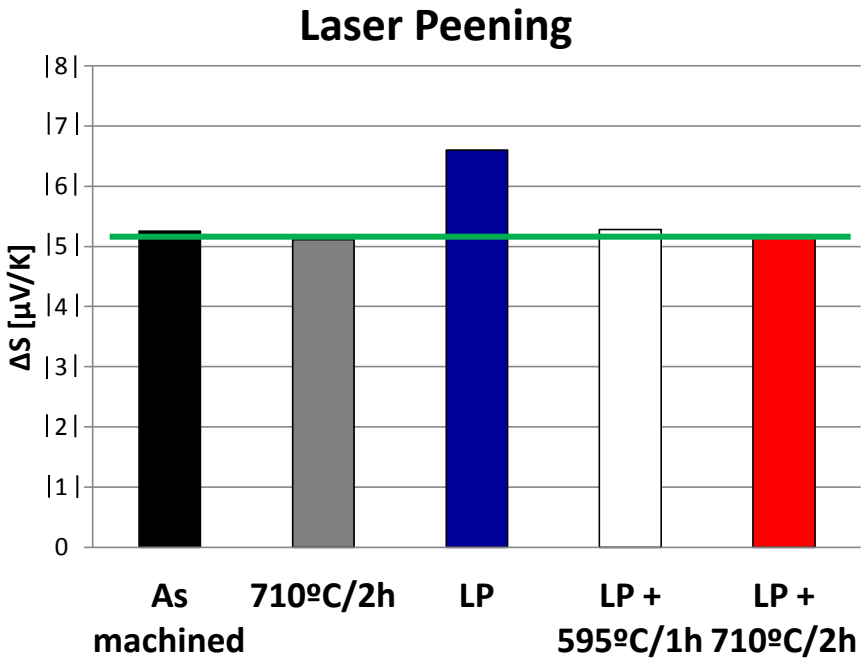
Sample	Ra (µm)
As machined	1.84 ± 0.05
710ºC / 2h	1.70 ± 0.10
Laser Peened	5.43 ± 0.40
595ºC /1h	5.67 ± 0.29
710ºC /2h	5.33 ± 0.31

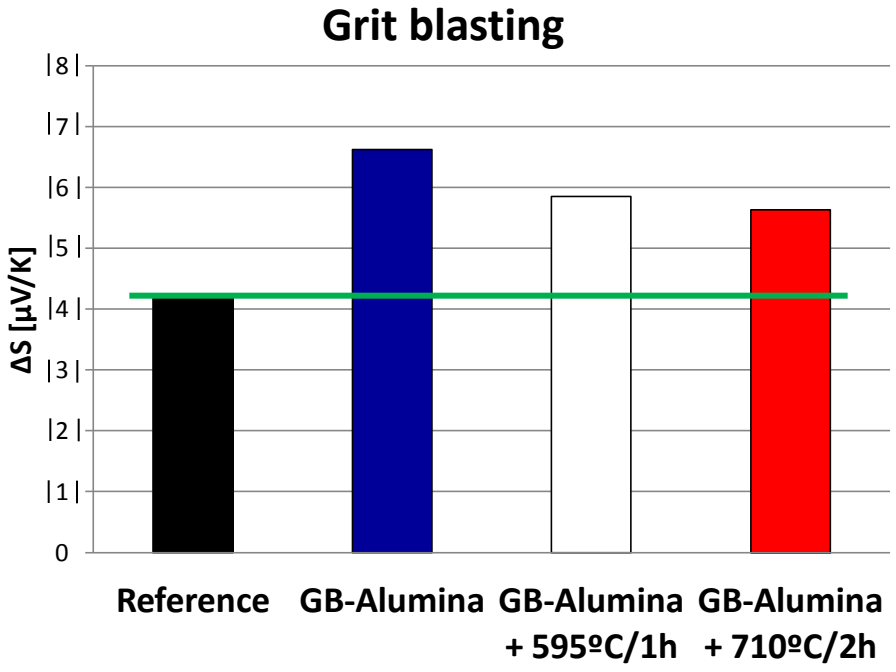
R_a { $GB\text{-}Al_2O_3 \approx 5.1\ \mu m$; $GB\text{-}ZrO_2 \approx 1.0\ \mu m$

Sub-surface Evaluation

TEP MEASUREMENTS: MICROSTRUCTURAL CHANGES

Hot tip method





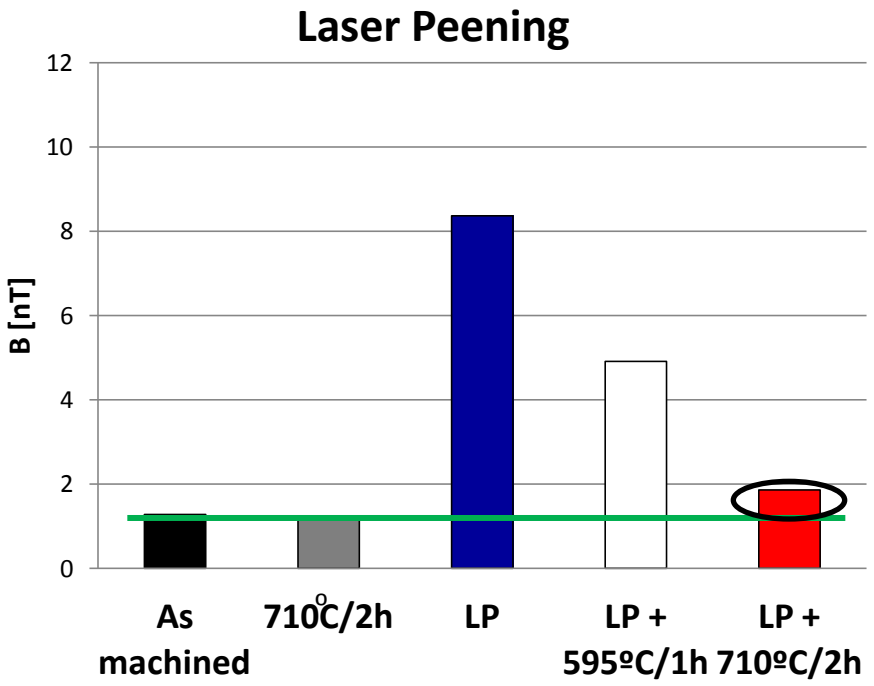
LP induces less plastic deformation than GB

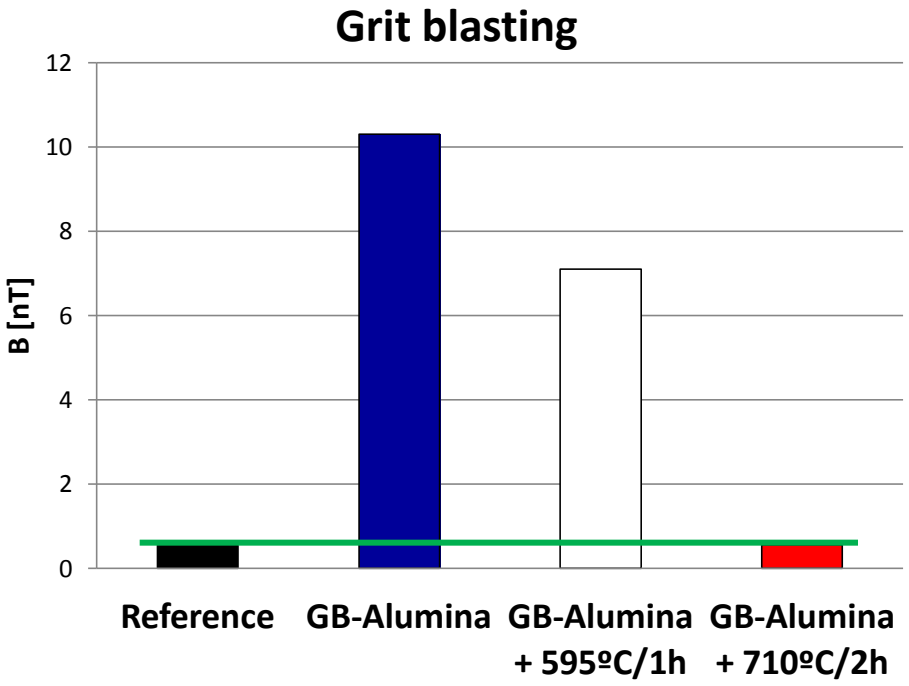
H. Carreón, S. Barriuso, M. Lieblich, J.L. González-Carrasco, J.A. Jimenez, F.G. Caballero.
Materials Science and Engineering C 33 (2013) 1417–1422

Sub-surface Evaluation

TEP MEASUREMENTS: RESIDUAL STRESS

Magnetic method





LP might induce higher residual stress than GB

H. Carreón, S. Barriuso, M. Lieblich, J.L. González-Carrasco, J.A. Jimenez, F.G. Caballero.
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CONCLUSIONS

• **Laser Peening without coating** is a good method to generate **biocompatible surfaces** with **roughness** of **clinical interest**.

• **Thermoelectric Power** measurements is a good method to evaluate in a **fast**, **non destructive** and **qualitative** way the **laser peening induced effects.**

• **Laser peening** induced effects on **Ti6Al4V** can be detected by **TEP** and the contribution of the **residual stress** can be **distinguished** from the **microstructural changes**.

• Strong support for these conclusions should be confirmed by **microstructural analyses** (SEM, TEM,…) and **residual stress measurements** (hole drilling, synchrotron).

CENIM CSIC

4th International Conference on Laser Peening and Related Phenomena

POLITÉCNICA

THANK YOU FOR YOUR ATTENTION

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