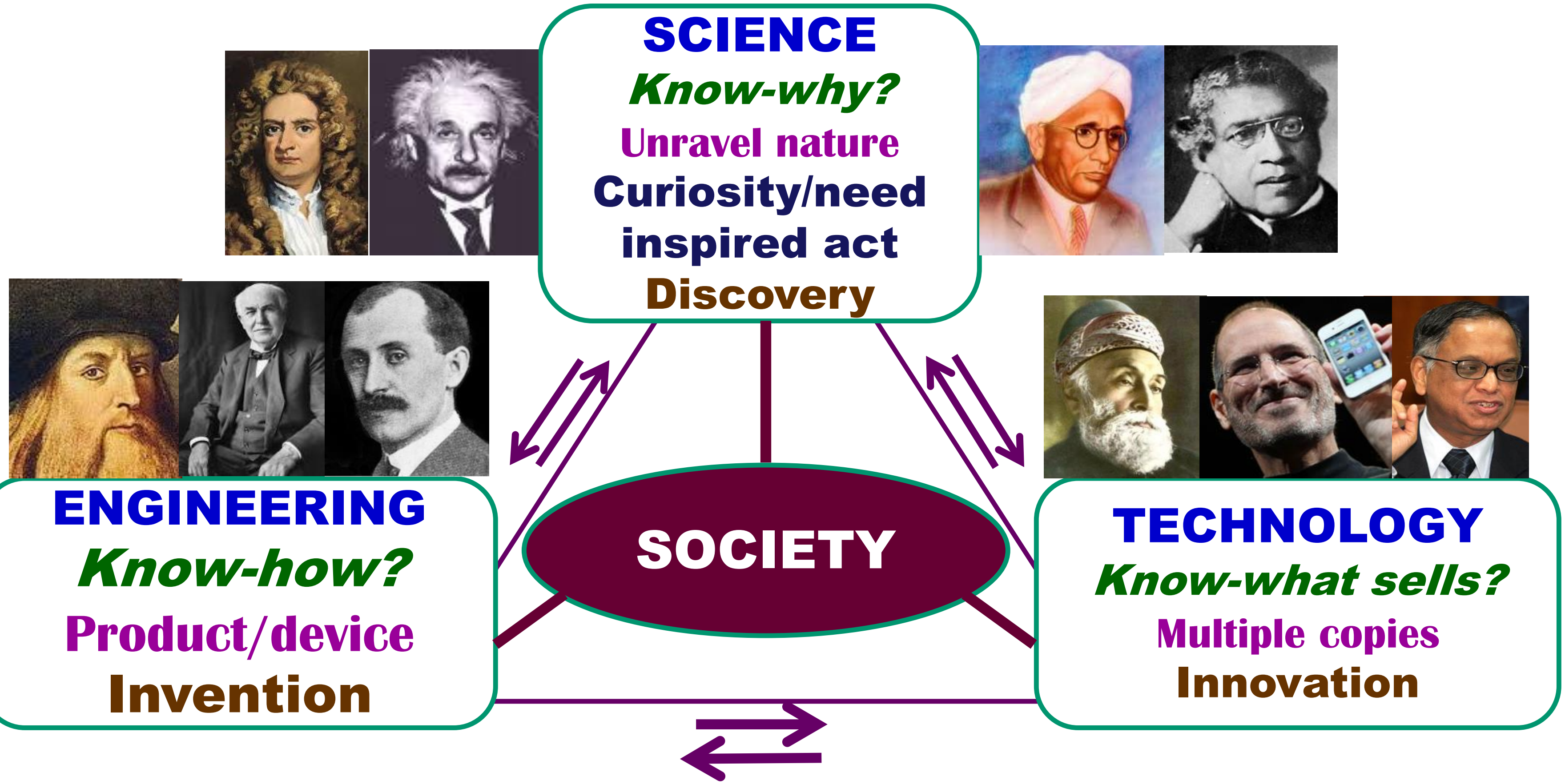
# THE PERPETUAL TRIAD



# LASER AIDED SURFACE ENGINEERING AND ADDITIVE MANUFACTURING OF STEEL

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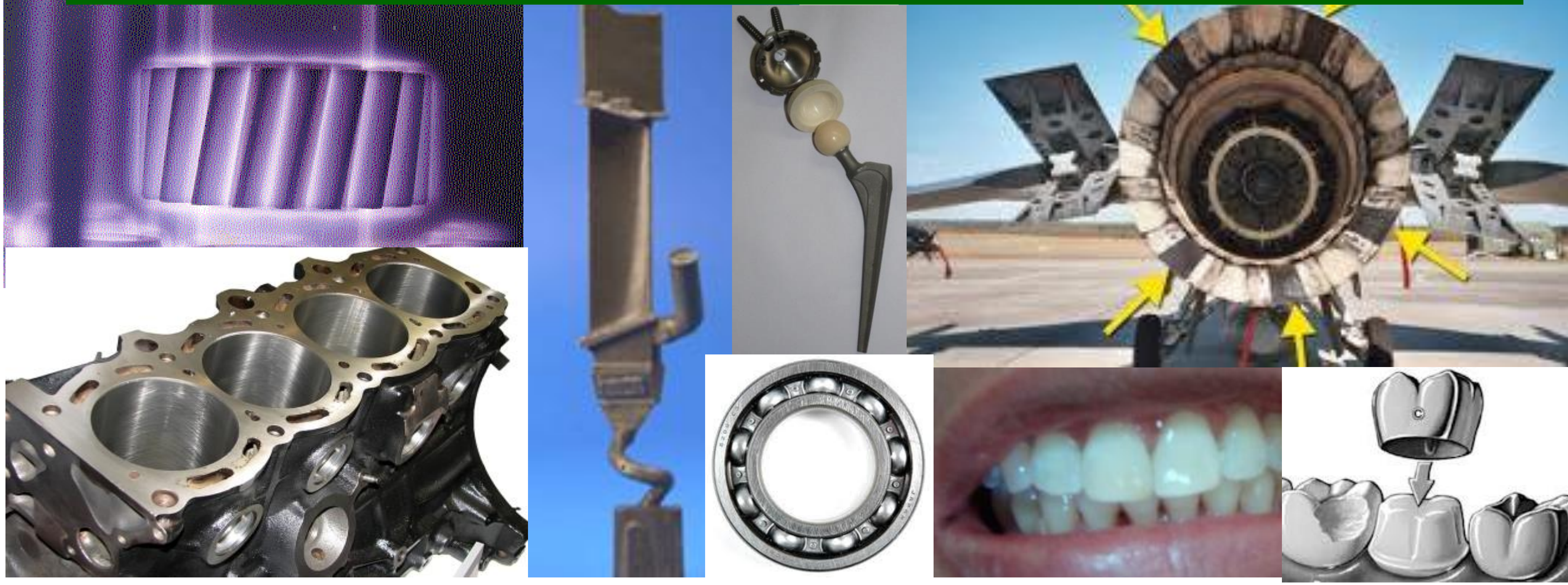
- **Surface degradation and failure**
- **Surface engineering – philosophy**
- **Basics of laser - matter interaction**
- **Laser assisted surface engineering**
  *Bearing/bainitic steel, ADI, H13 tool steel*
- **Laser assisted additive manufacturing (LAM)**
  *Genesis, fundamentals and scope of innovation*
- **Issues in direct manufacturing of steel components**

**Steel Technology Festival ♦ New Delhi ♦ 21Jan2020**

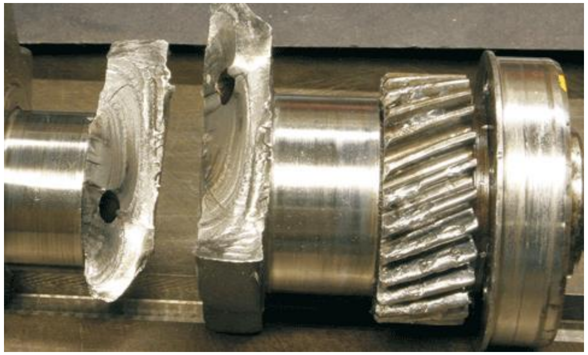
# ENGINEERING COMPONENTS AND SURFACES

*Laser Materials Processing, International Materials Reviews* **56** (2011) 341-388

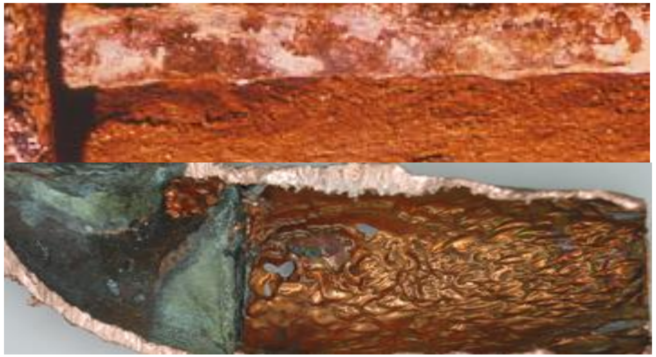


**Wear/Abrasion**


**Fretting Fatigue**



**Wet Corrosion**



# Surface Dependent Properties

**Physical**
Color, Roughness, Wetting
Emissivity

**Chemical**
Catalysis, Corrosion
Chemisorption, Oxidation

**Mechanical**
Hardness, Wear, Erosion
Friction, Fretting

## Surface Engineering Approach

**Material Removal**
(Machining, Polishing)

**Surface Modification**
(Alloying, Hardening)

**Material Addition**
(Deposition, Cladding)

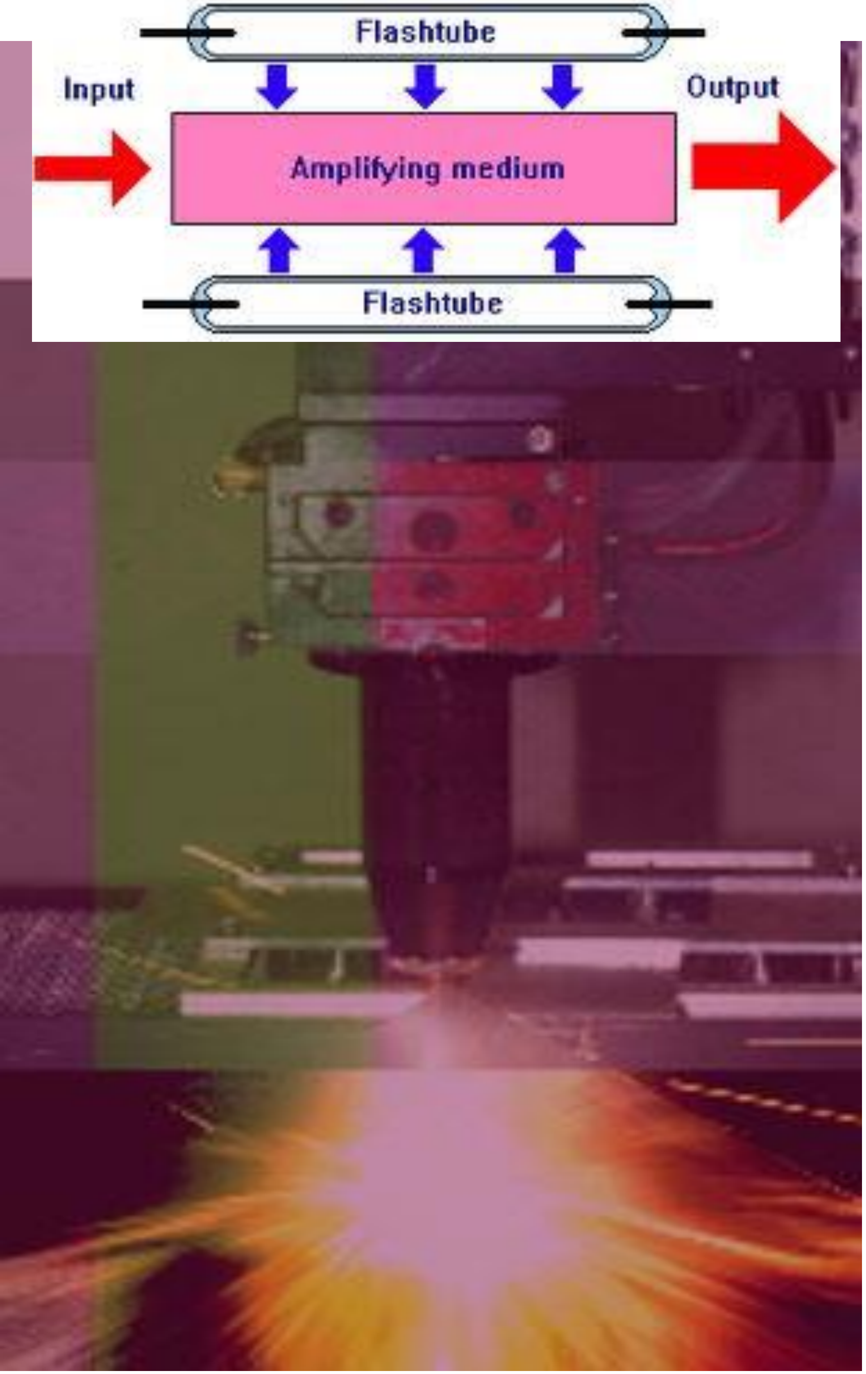
## Surface Engineering

*Tailoring the microstructure/composition of the near-surface region (nm-mm) to enhance surface-dependent properties*

**Conventional**
*Carburizing, Nitriding*
*Electroplating, Painting*
*Calorizing, Diffusion Coating*

**Directed Energy Beam Techniques**
*Ion beam, Electron beam,*
*Laser beam*

# Light Amplification by Stimulated Emission of Radiation



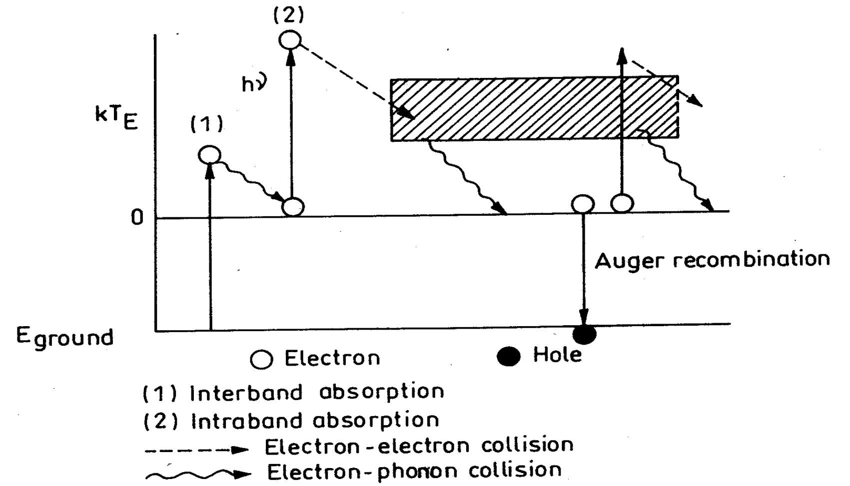

Why is it different from ordinary light?

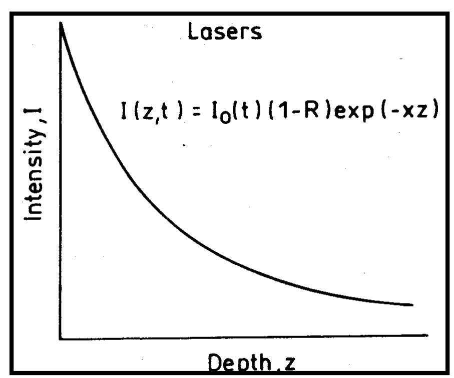
⇒ Coherent (both spatially and temporarily)

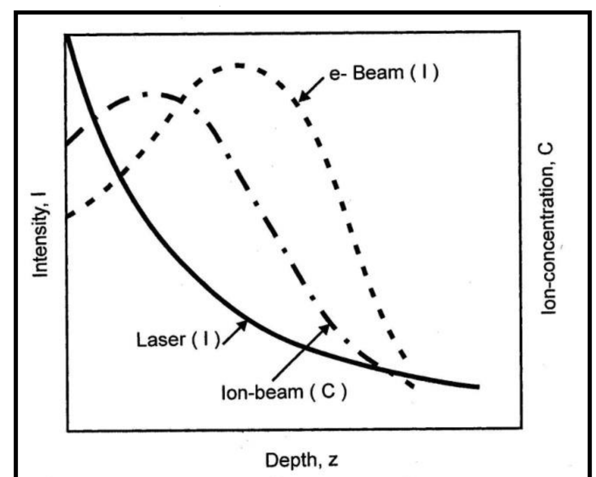
⇒ Monochromatic ($\Delta\lambda/\lambda = 10^{-10}$)

⇒ Low divergence (straight line)

⇒ High power density is achievable

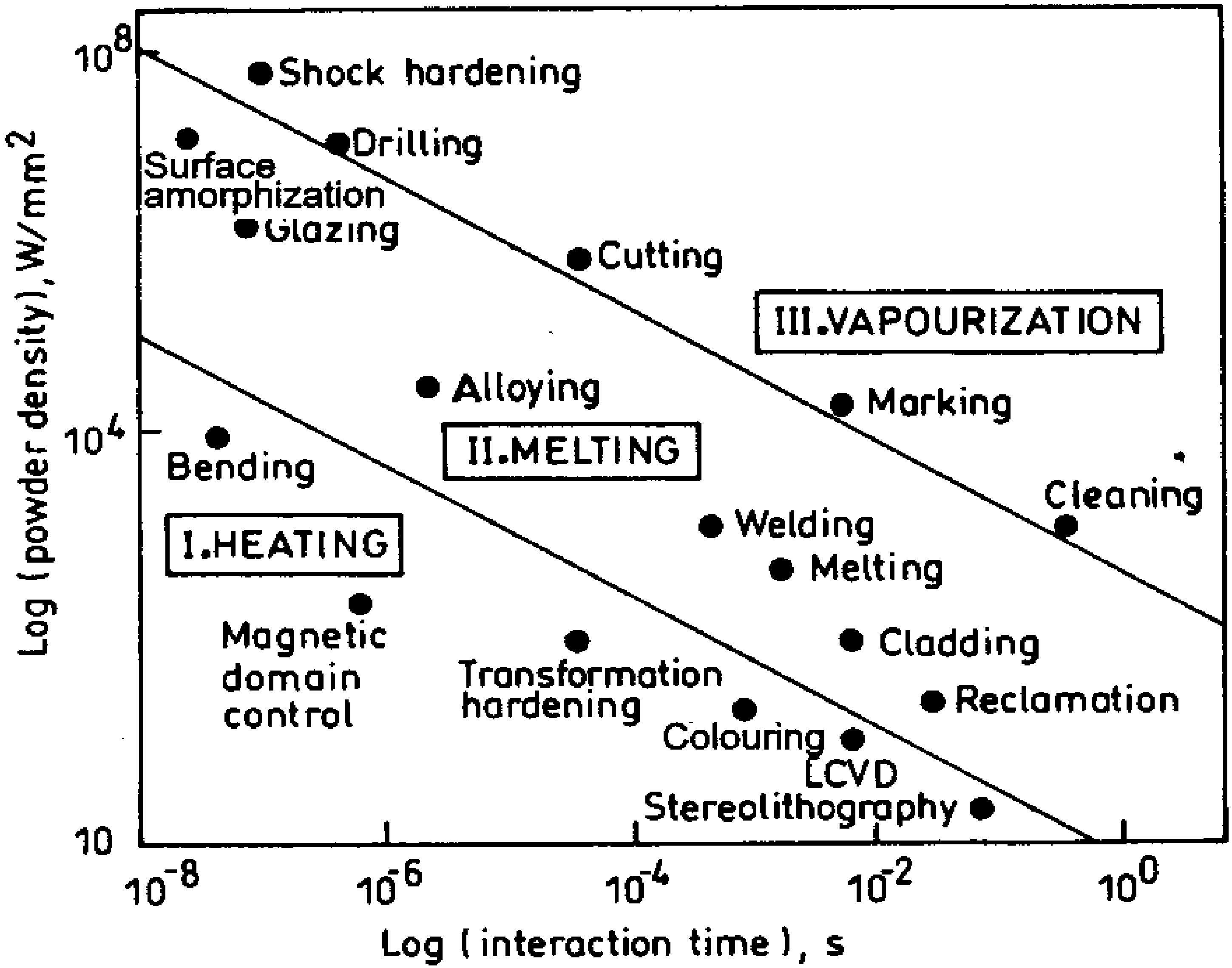



# LASER MATERIAL PROCESSING

# Lasers Assisted Material Processing



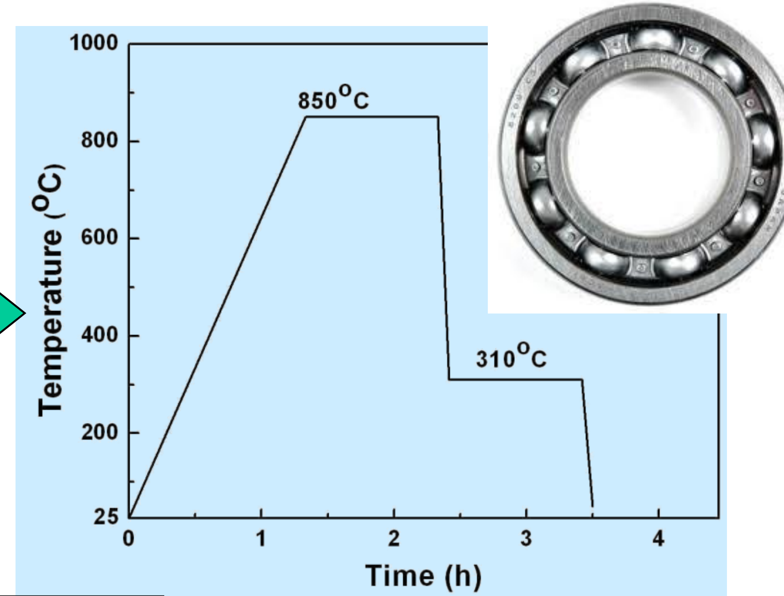

Dutta Majumdar and Manna, Laser Material Processing, *Sadhana-Academy Proceedings* 28 (2003) 495-562

# LSH of Austempered Low Alloy Steel

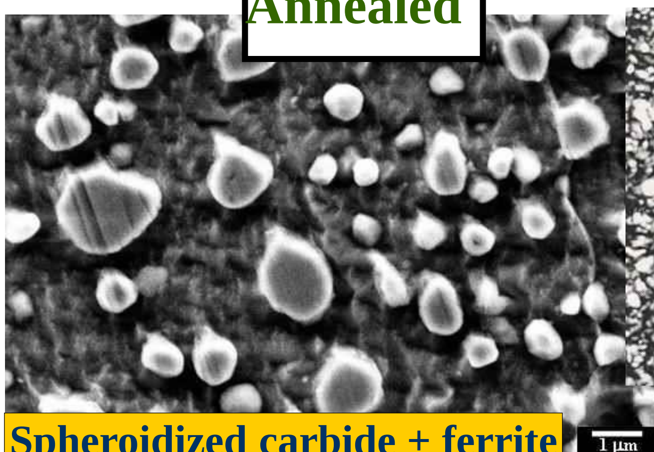
**AIM: Harder surface by LSH on tougher core**

Laser: $CO_2$
Power: 2.5 kW
Speed: 12–20 mm/s
De-focused beam
Shroud gas: $N_2$

Austempering
→ Sample preparation
→ Laser surface hardening (LSH)
→ Controlled removal of surface
→ XRD | FE-SEM | Hardness | Wear | Residual stress | Thermal profile modeling

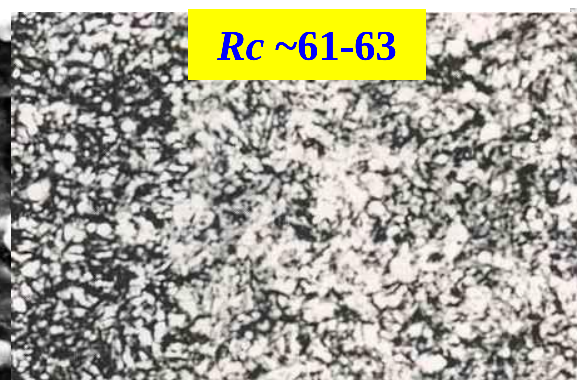



Annealed




Spheroidized carbide + ferrite

*Rc* ~61-63



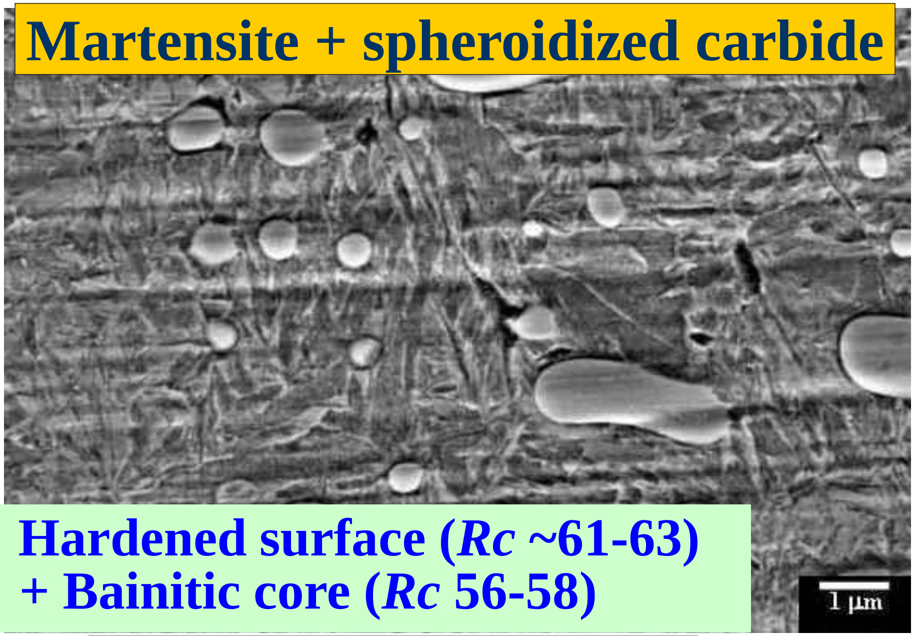
Hardened + Tempered

Austempered

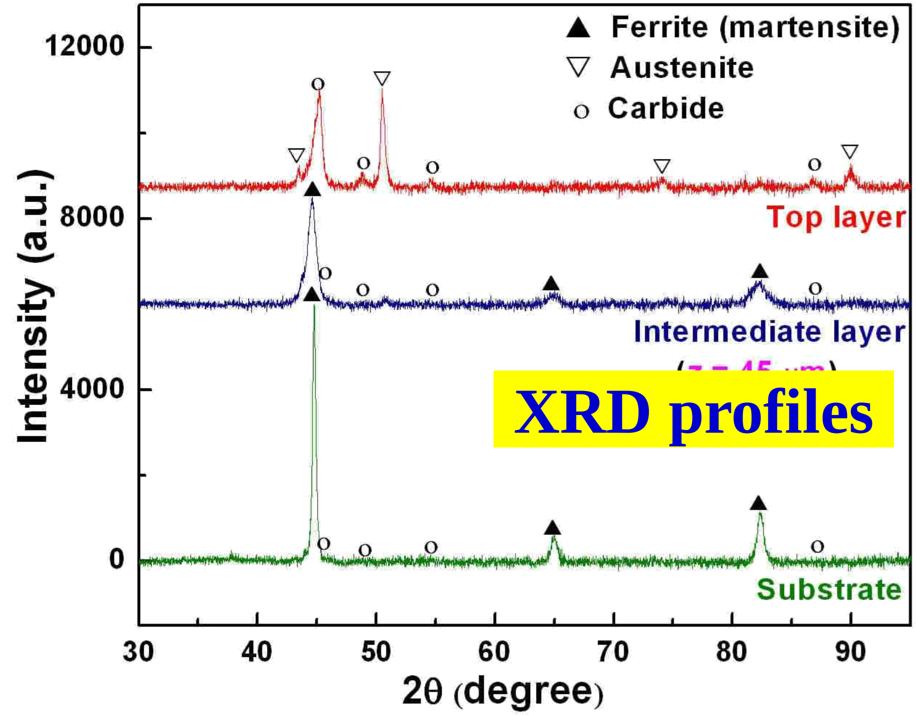

*Rc* ~56-58

Lower bainite + carbide

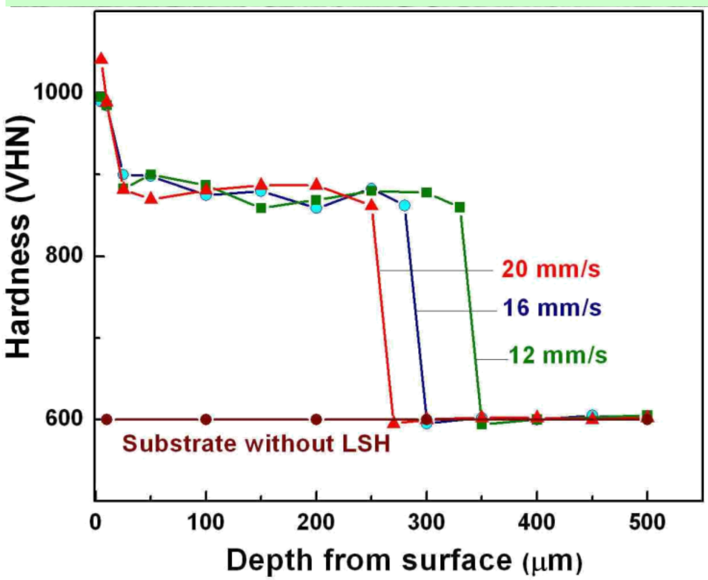
# MICROSTRUCTURE and XRD




**Hardened surface (*Rc* ~61-63)**
**+ Bainitic core (*Rc* 56-58)**

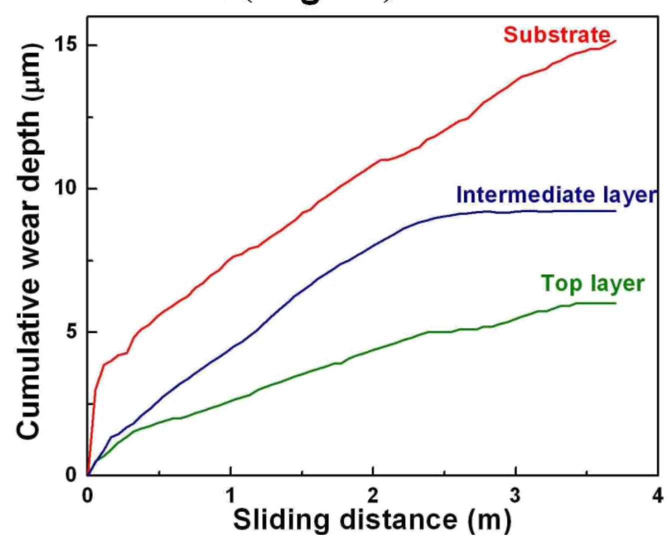



**XRD profiles**




**Microhardness profiles**

**Basu et al,**
**Scripta mater**
**56 (2007) 887**




**Wear test results**

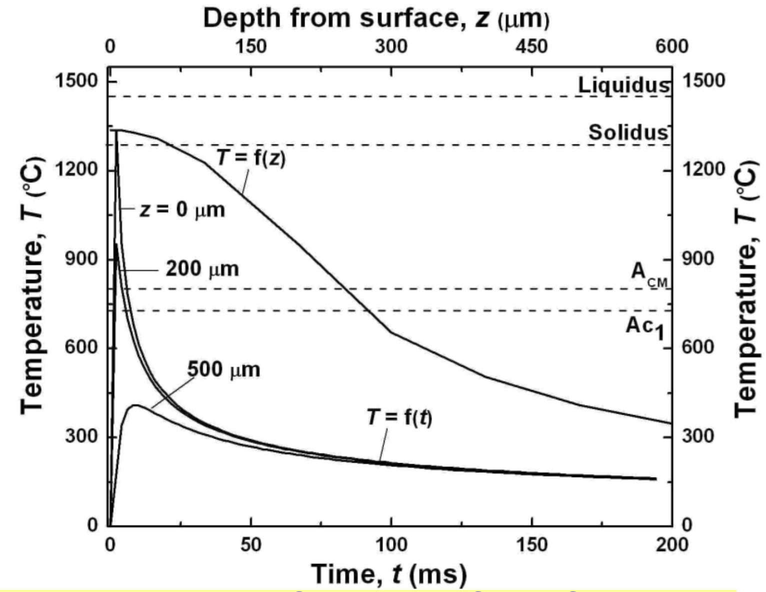
# THERMAL PROFILE MODELING

$$T - T_0 = \frac{Aq/v}{2\pi\lambda\left[t\left(t+t_0\right)\right]^{1/2}} \exp\left[-\frac{1}{4\alpha}\left\{\frac{z^2}{t} + \frac{y^2}{t+t_0}\right\}\right]$$

$T$ = Temperature of the substrate
$T_0$ = Initial temperature of the substrate
$A$ = Absorptivity at the sample surface
$q$ = Incident laser power
$\lambda$ = Thermal conductivity
$\alpha$ = Thermal diffusivity ($=\lambda/\rho c$)
$r$ = Density

$c$ = Specific heat
$v$ = Laser scan speed
$r$ = Radius of the beam
$t_0 = r2/4a$
$z$ = Vertical depth from the surface
$y$ = Perpendicular distance

[*After: *M. F. Ashby, K. E. Easterling, Acta. Metall. 32 (1984) 1935.*]

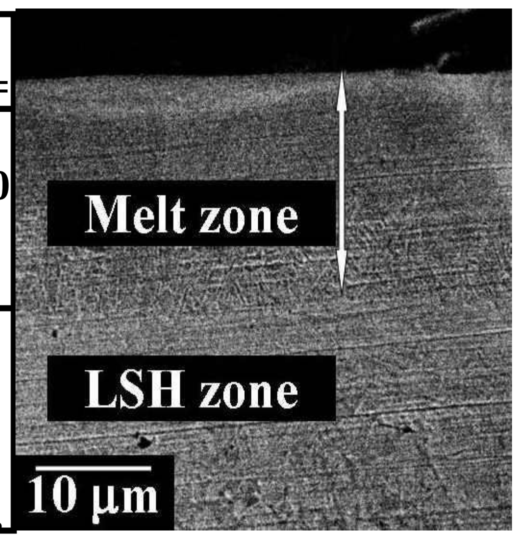



**Temperature profile as a function of time at different depths ($z$) from surface for scan speed 16 mm/s and variation of temperature as a function of depth from surface ($z$)**

**Melt zone**, ledeburitic, residual stress = 800 MPa, hardness = 900-1000 VHN, thickness = 10-30 μm

**LSH zone**, martensitic, residual stress = -400 MPa, hardness = ~850-900 VHN, thickness = 250-300 μm

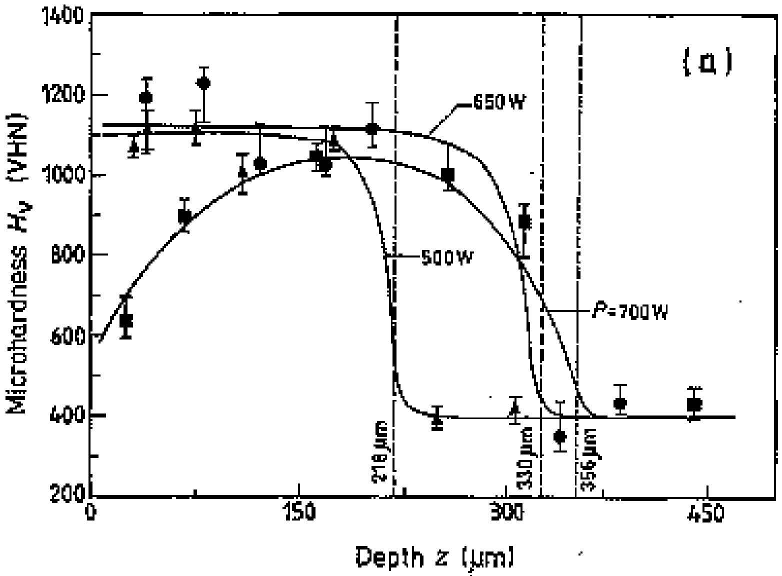
**Substrate**, bainitic, hardness = ~600 VHN



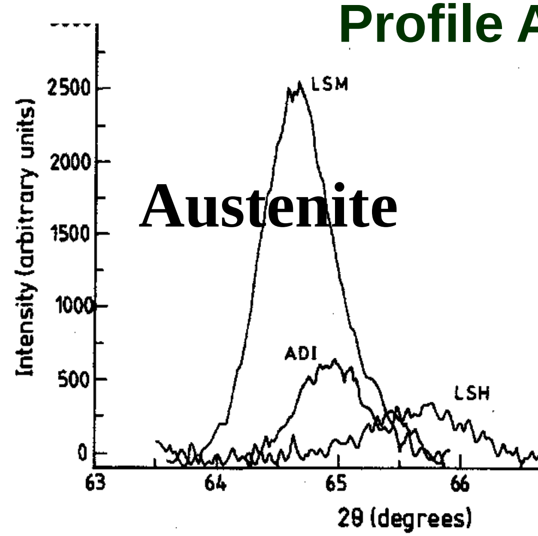

*Basu et al, Scripta Mater.* **56 (2007) 887-890**

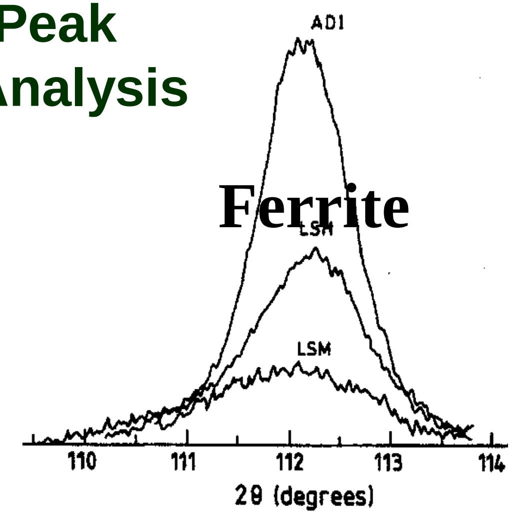
**Cross sectional view**

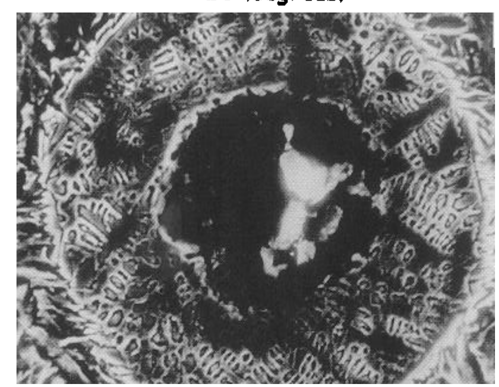
# Hardness Profile after LSM and LSH



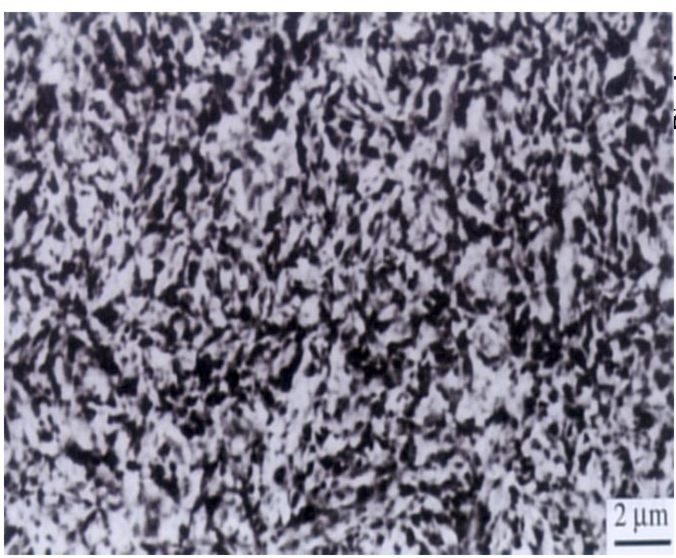

# XRD Peak Profile Analysis

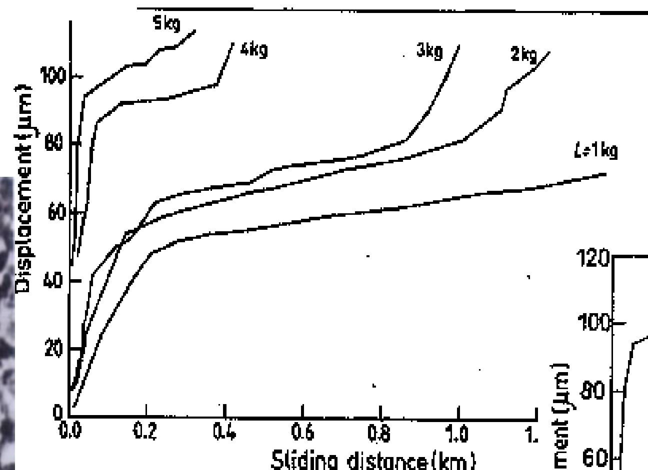


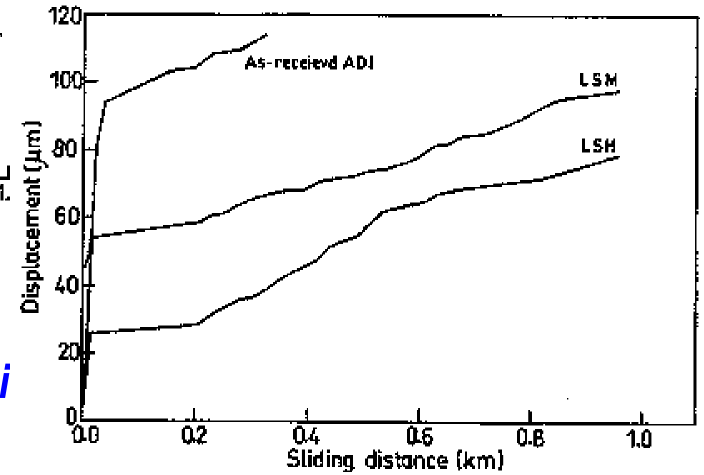



# Martensitic Surface after LSH

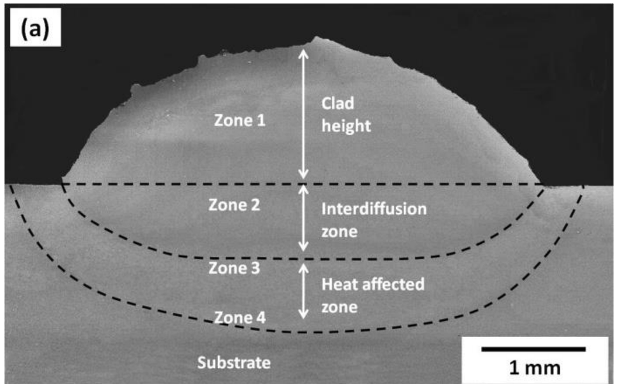


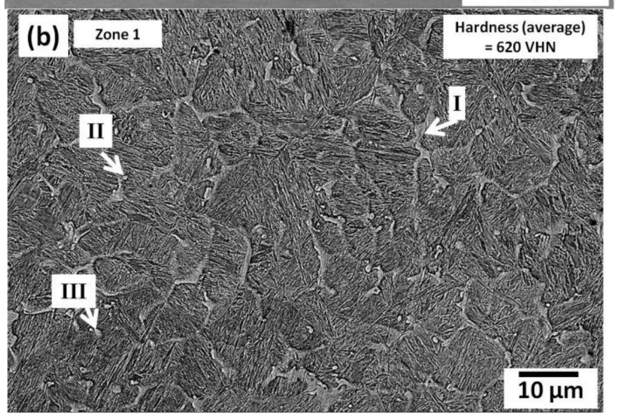




Roy and Manna, *Mater. Sci Eng.* A297 (2001) 85-93

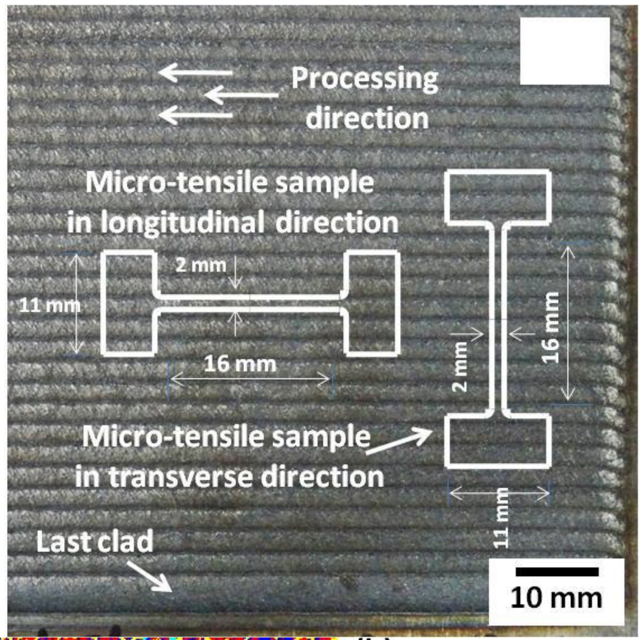


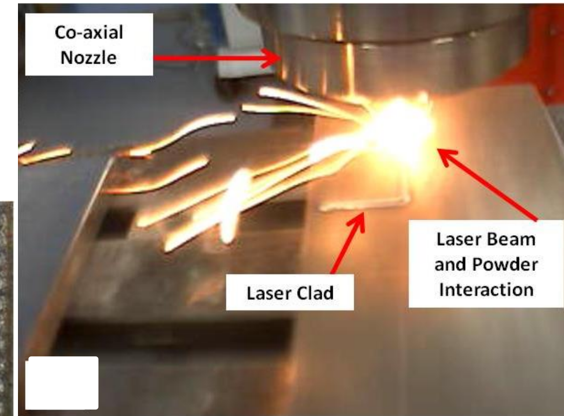
# AISI H13 Tool Steel: Die Material for PDC



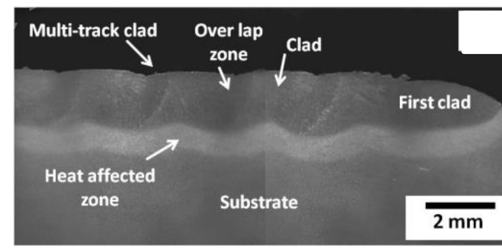



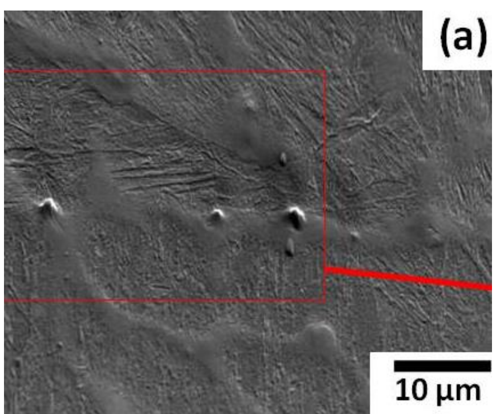

**Powder**: H13 tool steel
**System**: 6 kW diode laser
**Spot** $\phi$: 3 mm

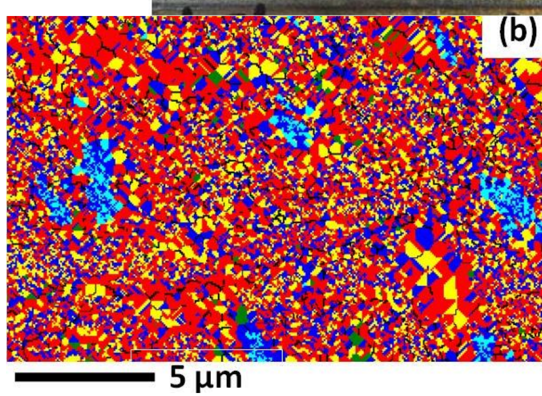


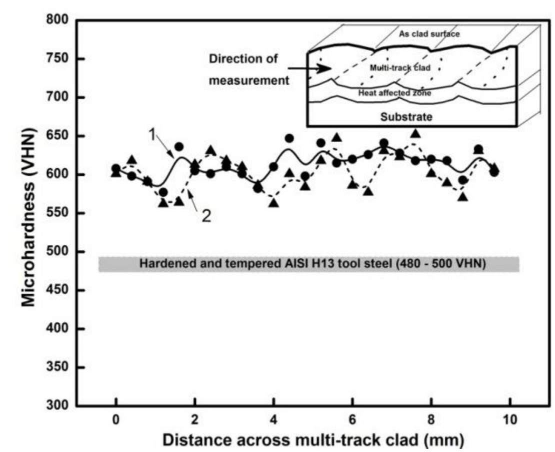

## Laser cladding




**Multi-track laser clad**




Telasang et al., Surf Coat Tech, 258 (2014) 1108–18; 261 (2015) 69-78

# LAM Processes for Components

## Additive Manufacturing

## In the Global Arena

"Additive manufacturing has the potential to revolutionize the way we make almost everything". 2013 State of the Union Address, US President Obama. "… establish 15 additive manufacturing hubs in US".


1st in Ohio, early 2014

**LAM Processes**

**A] Liquid based LAM**

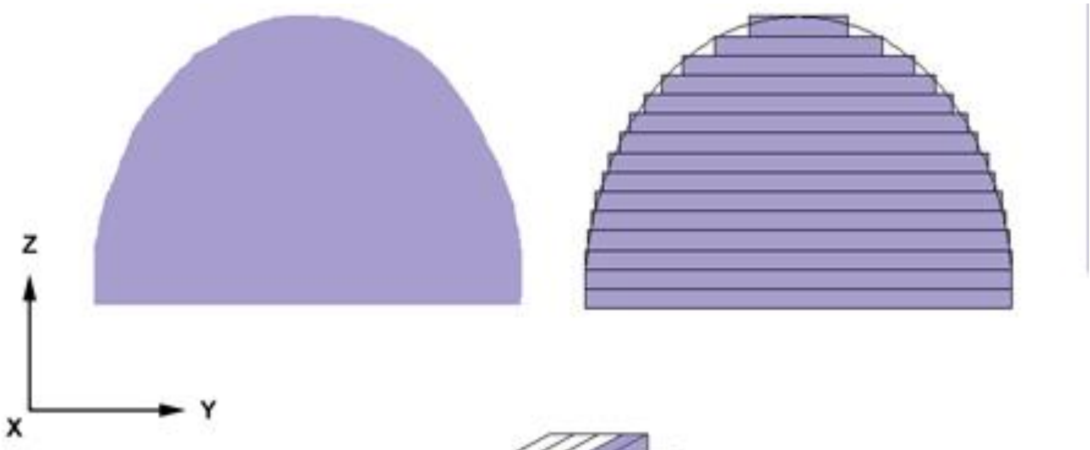
**B] Powder based LAM**

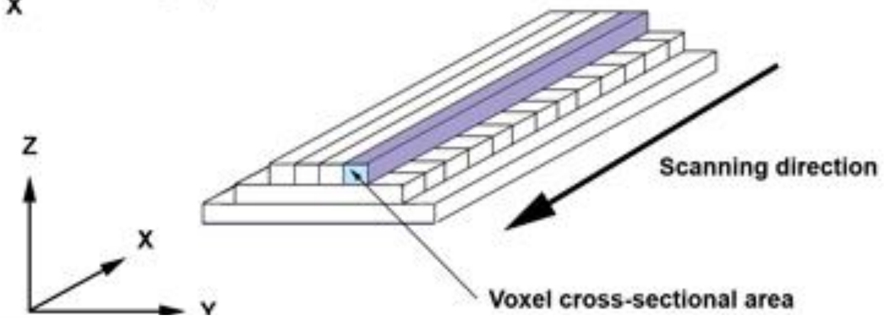
**C] Solid based LAM**

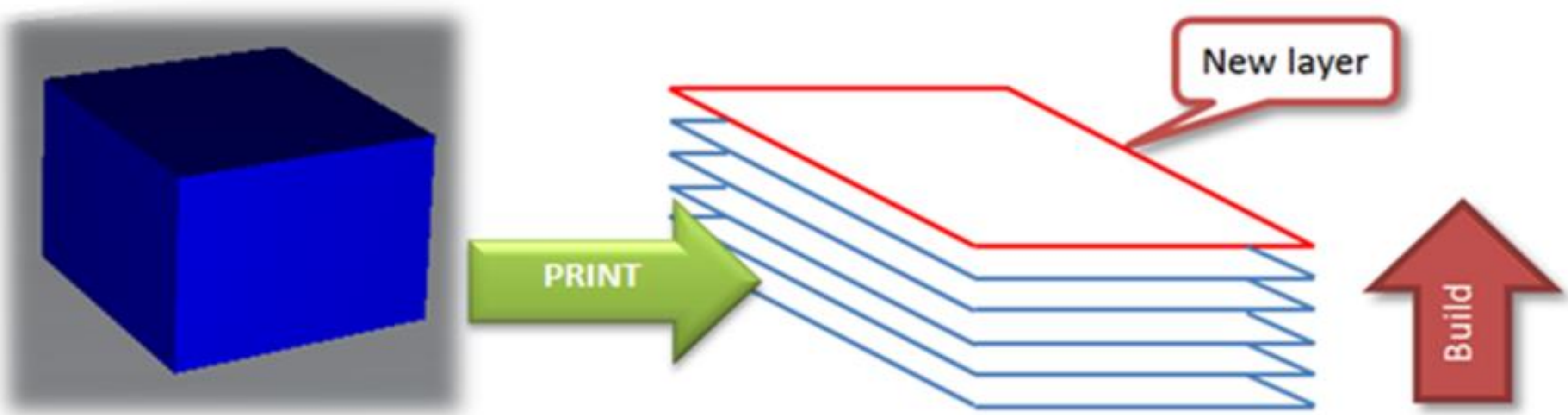
## Materials:

**Thermopalstics, Photoplastics, Stainless steel, Co-Cr, Nimonic, Ti6Al4V, Ceramics**

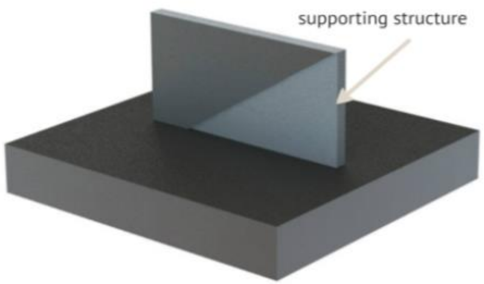
# Laser Additive Manufacturing

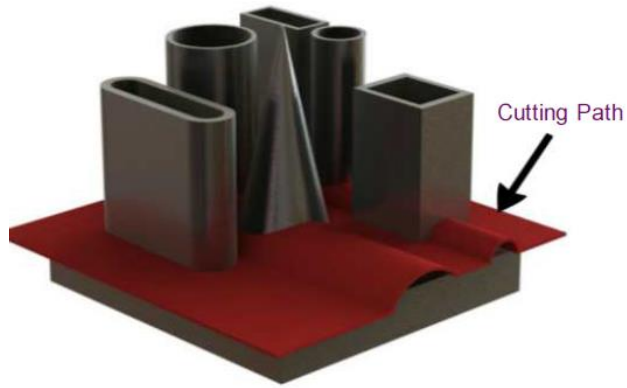


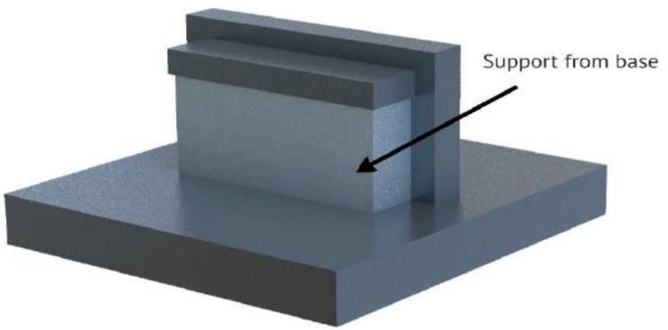
# Components by LAM

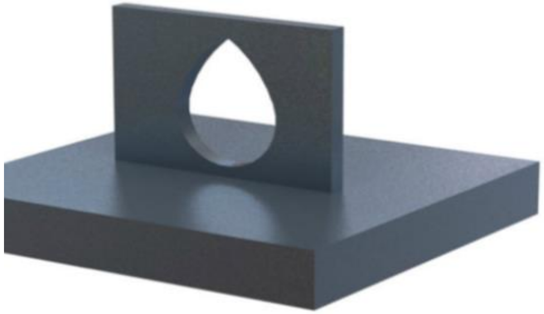




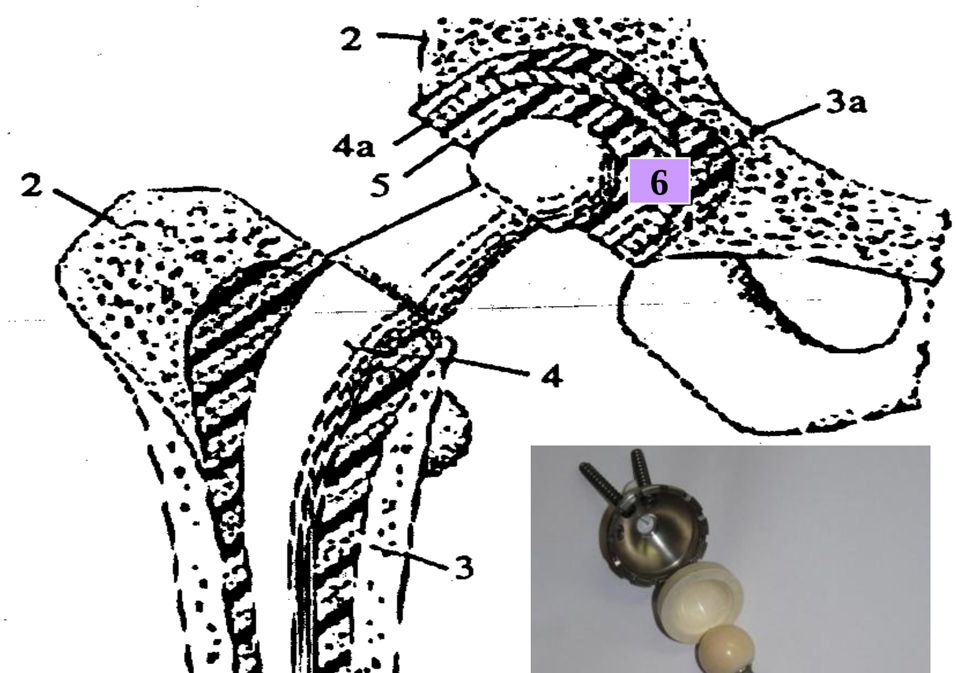
IN718



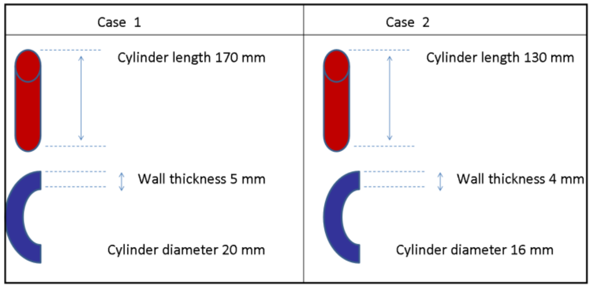

Ti64

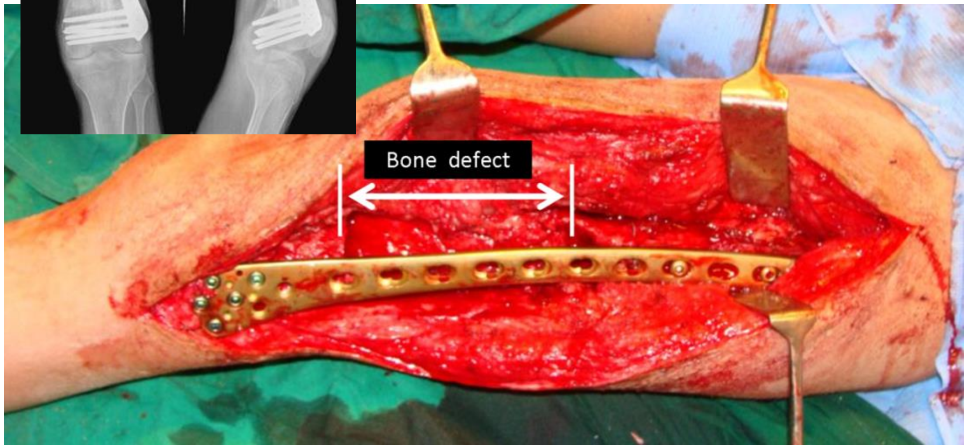
# Development of Compositionally Graded Component – Human Prosthesis/Implants





1. Cortical bone
2. Trabecular bone
3. Bone cement
4. Femoral prosthesis
5. Frame of acetabular cup
6. Acetabular cup and balls




**Artificial hip replacement**

## Concluding remarks:

1. Laser is also a versatile tool for developing graded composition, microstructure and functions by LSE and/or LAM
2. LAM is better suited for making complex shape/structure/design
3. Key issues for making LAM viable: atomized powder, flexibility for changing parameters/approach, cheaper machines/consumables, greater degree of automation, and reduction of defects/anisotropy

## Specific Challenges in LAM:

- Defects due to fluctuations in laser power delivery with time
- All existing machines are open-loop enabling sequential operation
- Anisotropy in mechanical properties (along x-y-z) – small beam size
- Heterogeneity in microstructure due to local variation in beam power

Acknowledgement: Students, Colleagues, Collaborators, Sponsors

*Thank you very much !*