UNIT II & III
1. Tribo-surfaces and their characterisation
2. Surface treatment techniques & applications

Lecture by

Dr. Mukund Dutt Sharma, Assistant Professor

Department of Mechanical Engineering

National Institute of Technology

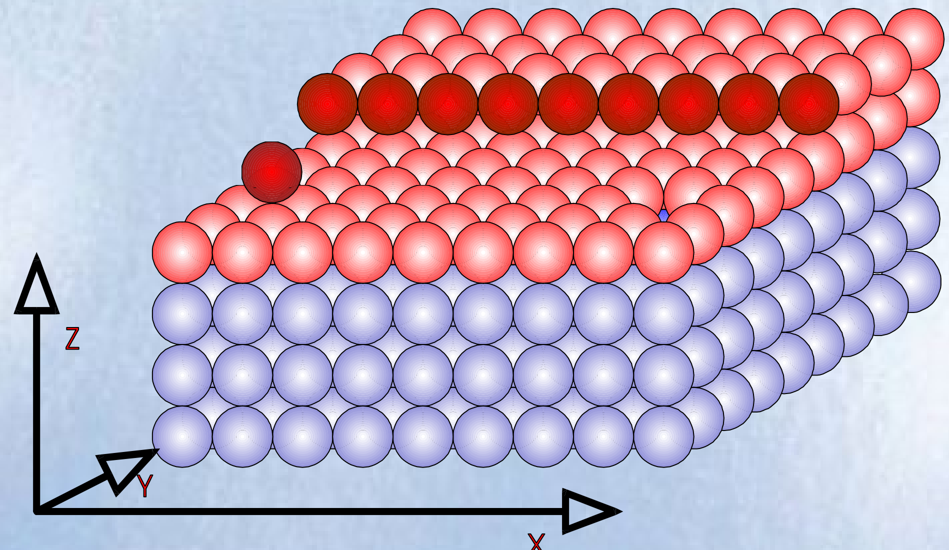
Srinagar – 190 006 (J & K) India

E-mail: mukund.sharma@nitsri.net

Website: http://new.nitsri.ac.in/Department/Department_FacultyProfile.aspx?nEmpID=egi

Surfaces

A surface is made by a sudden termination of the bulk structure. The bonding that was involved in the bulk lattice (for a solid) or liquid is severed to produce the interface.



Since it requires energy to terminate the bonding, the surface is **energetically** less stable than the bulk.

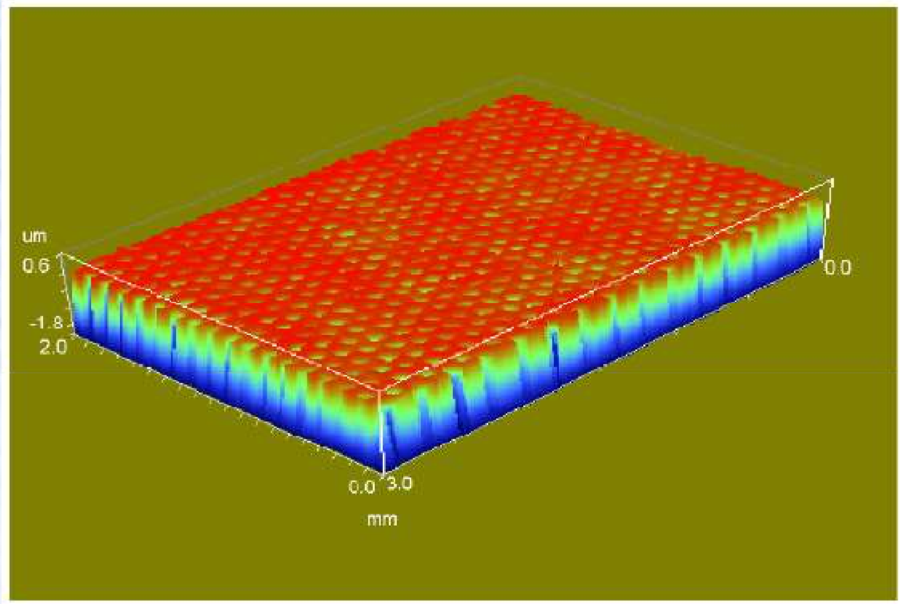
This energy is known as the **surface free energy**. In the case of liquid interfaces, this energy is called **surface tension**.

Why Surfaces?

- Properties different from that of the bulk
- Have major impact on several areas including semiconductors, corrosion, detergent, and *TRIBOLOGY*
- Specialised techniques required to study topography, composition and chemistry of surfaces

Significance of Surfaces in Tribology

- friction
- wear
- effectiveness of lubricants
- surface defects and initiation of cracks
- thermal and electrical conductivities



Ra= 0.1987 μm, Rq= 0.304 μ m, Rz= 10.04 μ m

Surface Defects Caused During Manufacturing

- Crack
  internal/external
- Craters
- Folds/Seams/Laps
- Heat Affected Zone
  thermal cycling w/o melting
- Inclusions
- Residual stresses
- Splatter
- Intergranular attack
- Metallurgical transformations
  temp., press., cycling
- Plastic deformation
  worn tools
- Pits
  shallow surface depressions

Surface Characterisation

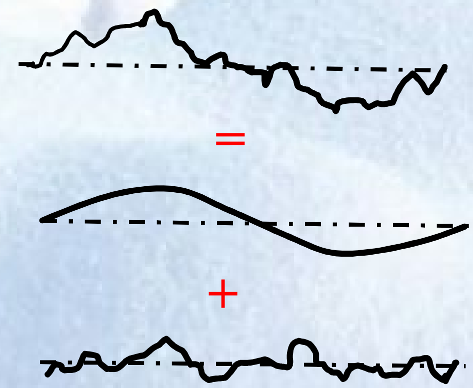
- ❖ General features of surface
  - Appearance
  - Shape of surface
  - – Anisotropy ?
- ❖ Mechanical properties
  - Modulus
  - Yield Strength
  - Hardness
  - Toughness....
  - Stresses and strains
- ❖ Chemistry of surface
  - Elements present
  - Phase distribution

- ❖ **Localised defects**
  - Any local changes in
    - Shape
    - Mechanical properties
    - Chemistry
  - Cracks

The Origin of Surface Irregularities

- The production process
  - Turning
  - Grinding
  - Polishing
- The material structure
  - Brittleness
  - Atomic structure
- The use of the surfaces
  - Wear
  - Running-in
  - Corrosion

The Spectrum of Wavelengths

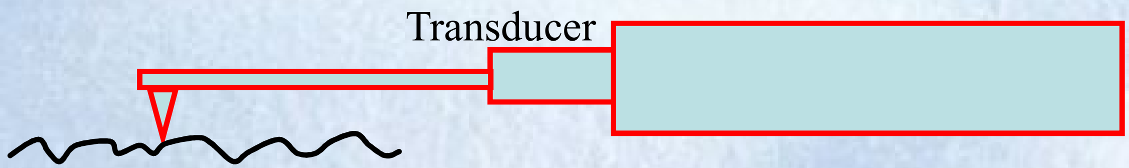


- Form
  - long wavelengths
  - >1000 times its amplitude
- Waviness
  - intermediate wavelengths
  - ratio between wavelength and its amplitude 100:1 - 1000:1
- Roughness
  - Short wavelengths

There is no clear limit between waviness and roughness – it depends on the measurement's sampling length and the filtering technique!

Surface Topography Measurement Methods

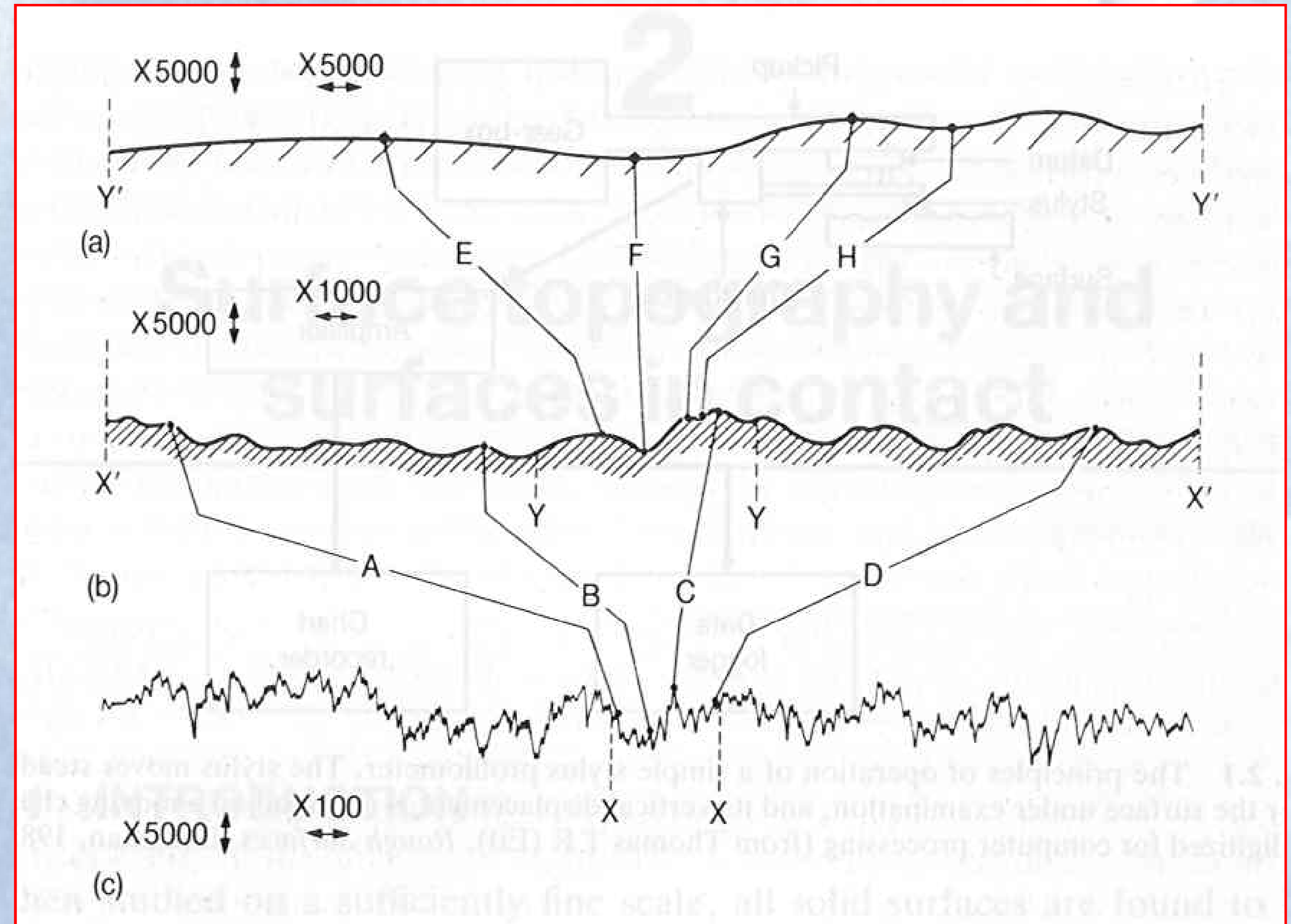
- Stylus profilometers (2D+1D)



- Optical methods (3D)
  - Interferrometry
- Scanning probe microscopy (2D+1D)
  - Scanning tunneling microscopy (STM)
  - Atomic force microscopy (AFM)

Surface topography measurements are never exact. All different Techniques give different answers. Even the use of the same technique at different laboratories!

Surfaces are Flatter Than One Expect

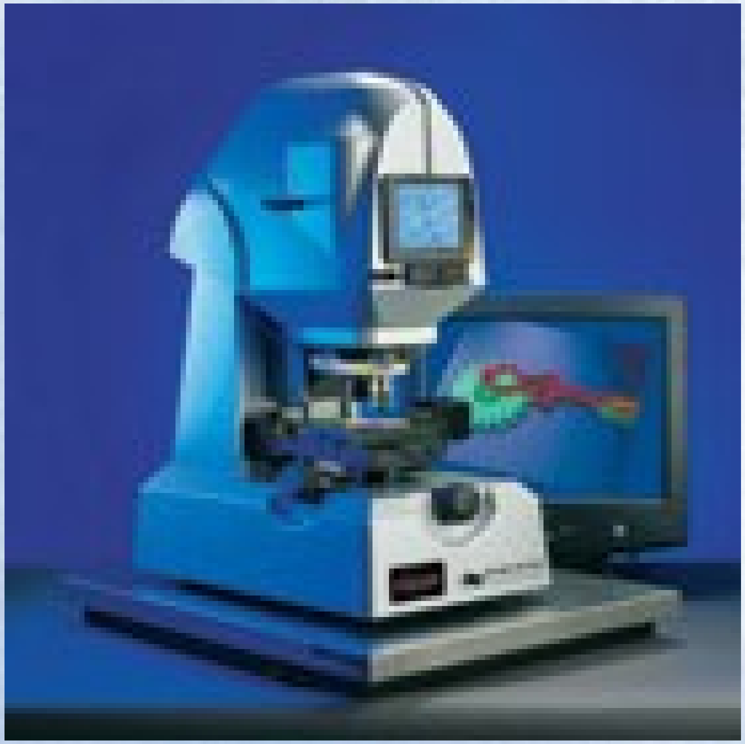


Asperity slopes are rarely steeper than 10°

Problems Encountered in Surface Topography Measurements

- **Stylus profilometers**
  - The tip radius (a few μm) is too large to resolve very fine irregularities
  - Might damage the surface (replication might be the solution)
- **Optical methods**
  - Expensive equipment
  - Thin films on the surface might cause errors
- **Scanning probe microscopy**
  - Expensive and sensitive equipment
  - Measurement on very small areas might lead to mis-interpretations

3D optical surface profiler (Wyko NT1100)



Optical Method – Turned Surface

Indexator 3-Dimensional Interactive Display

Date: 09/10/2001

Time: 12:45:09

Surface Stats:

Ra: 1.22 um

Rq: 1.39 um

Rt: 7.03 um

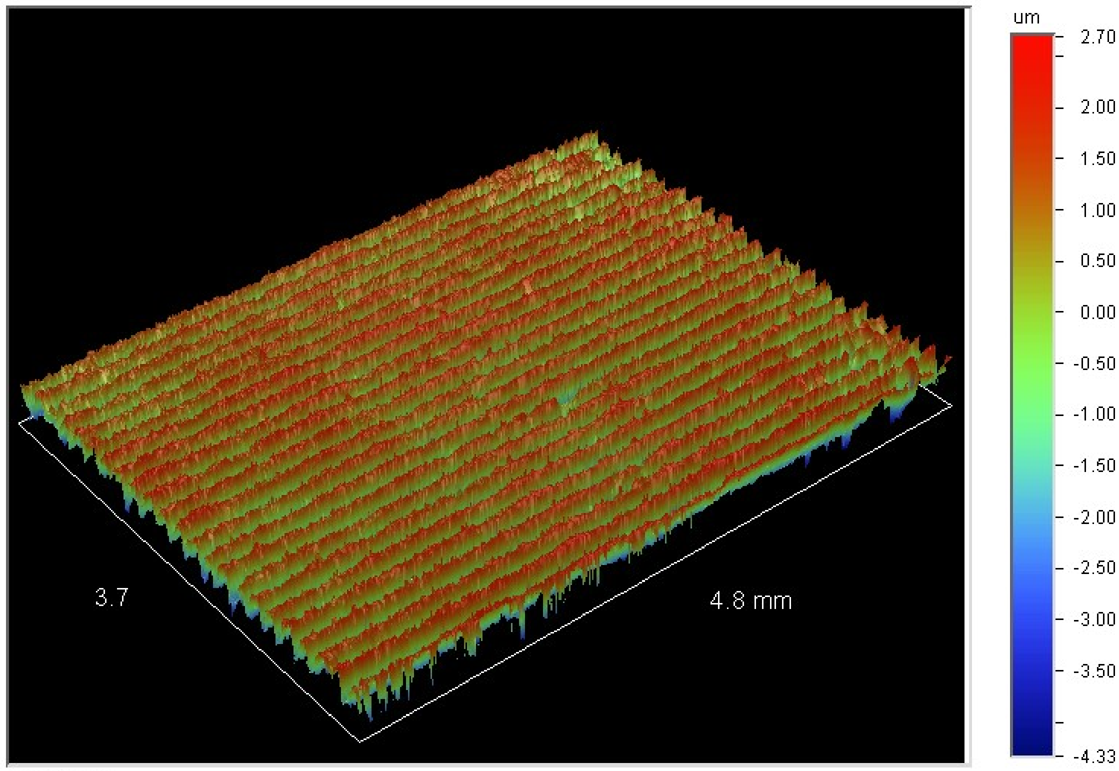
Measurement Info:

Magnification: 1.28

Measurement Mode: VSI

Sampling: 6.57 um

Array Size: 736 X 480



Title: 0725 S-ring GV14

Optical Method – Milled Surface

Indexator **3-Dimensional Interactive Display**

Date: 03/10/2001
Time: 15:32:34

Surface Stats:

Ra: 0.49 um

Rq: 0.61 um

Rt: 4.04 um

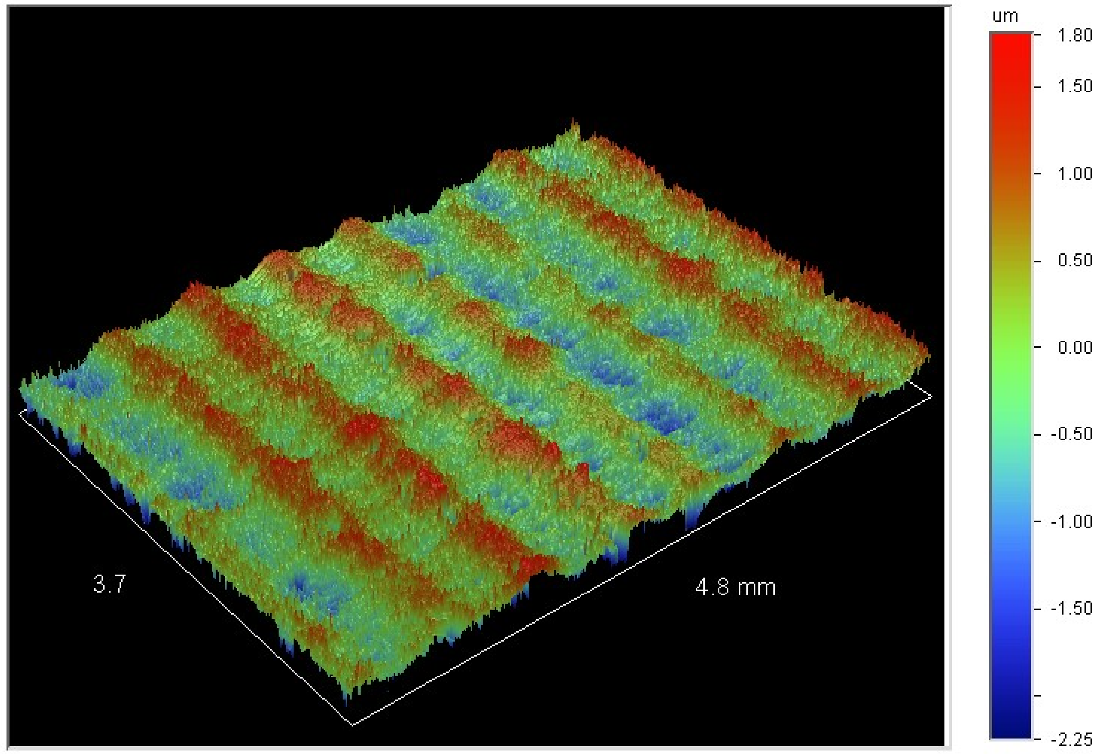
Measurement Info:

Magnification: 1.28

Measurement Mode: VSI

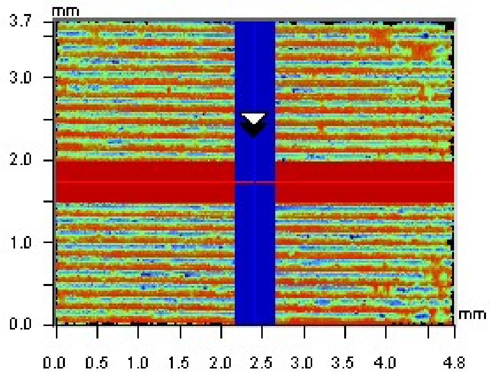
Sampling: 6.57 um

Array Size: 736 X 480



Title: 0725 S-ring GV14

Indexator



X	2.41	-	-	mm
Y	1.74	-	-	mm
Ht	-3.15	-	-	um
Dist			-	mm
Angle			-	°

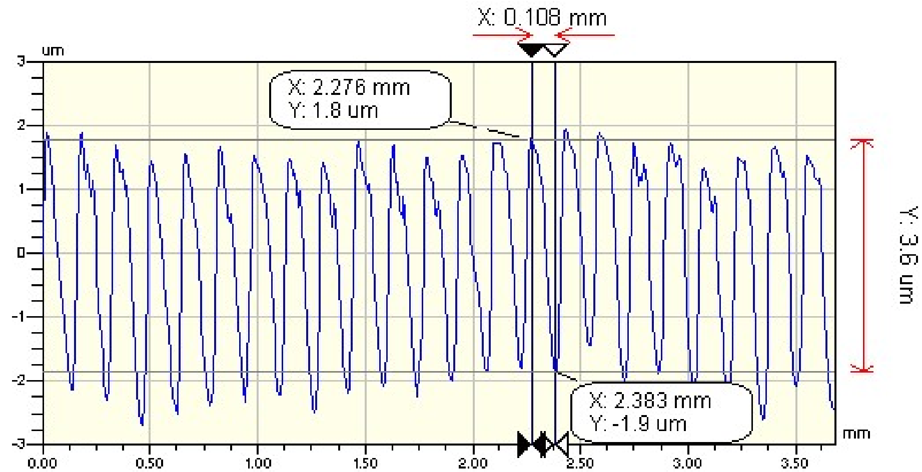
Title: 0725 S-ring GV14

X Profile

Rq	0.21	um
Ra	0.16	um
Rt	1.38	um
Rp	0.81	um
Rv	-0.58	um

Angle	-11.95	mdeg
Curve	44.63	m
Terms	None	
Avg Ht	-0.04	um
Area	-208.08	um2

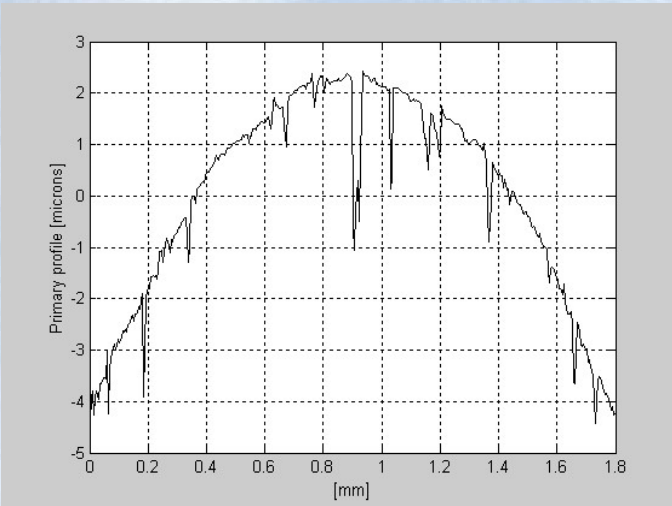
Y Profile



Rq	1.28	um
Ra	1.13	um
Rt	3.64	um
Rp	1.77	um
Rv	-1.87	um

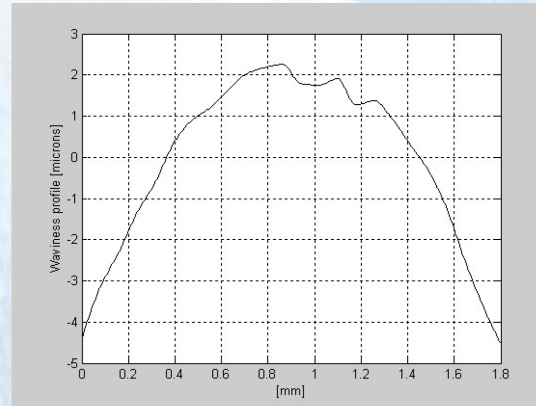
Angle	-1.94	deg
Curve	-1.70	mm
Terms	None	
Avg Ht	0.27	um
Area	29.32	um2

2D surface profiles

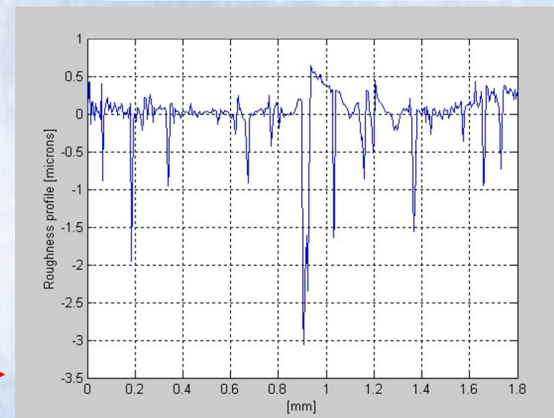


Primary profile

Filter

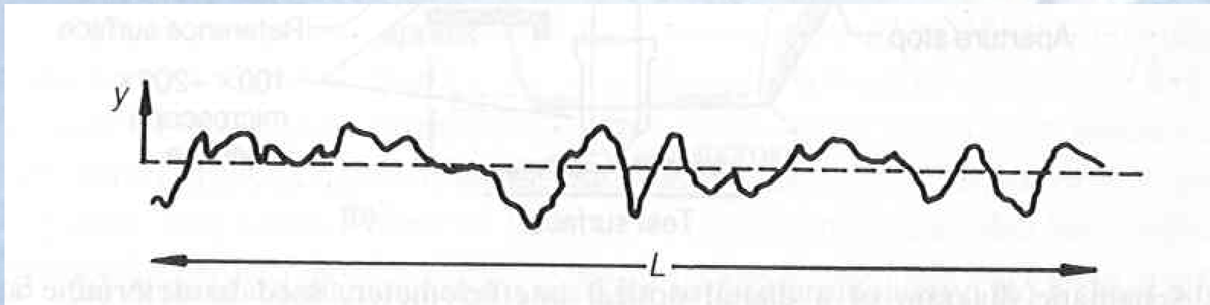


Waviness profile



Roughness profile

Average Roughness Parameters



- Average roughness, $\boldsymbol{R_a}$:

$$R_a = \frac{1}{L}\int_0^L |y(x)|\,dx$$

- R.M.S roughness, $\boldsymbol{R_q}$:

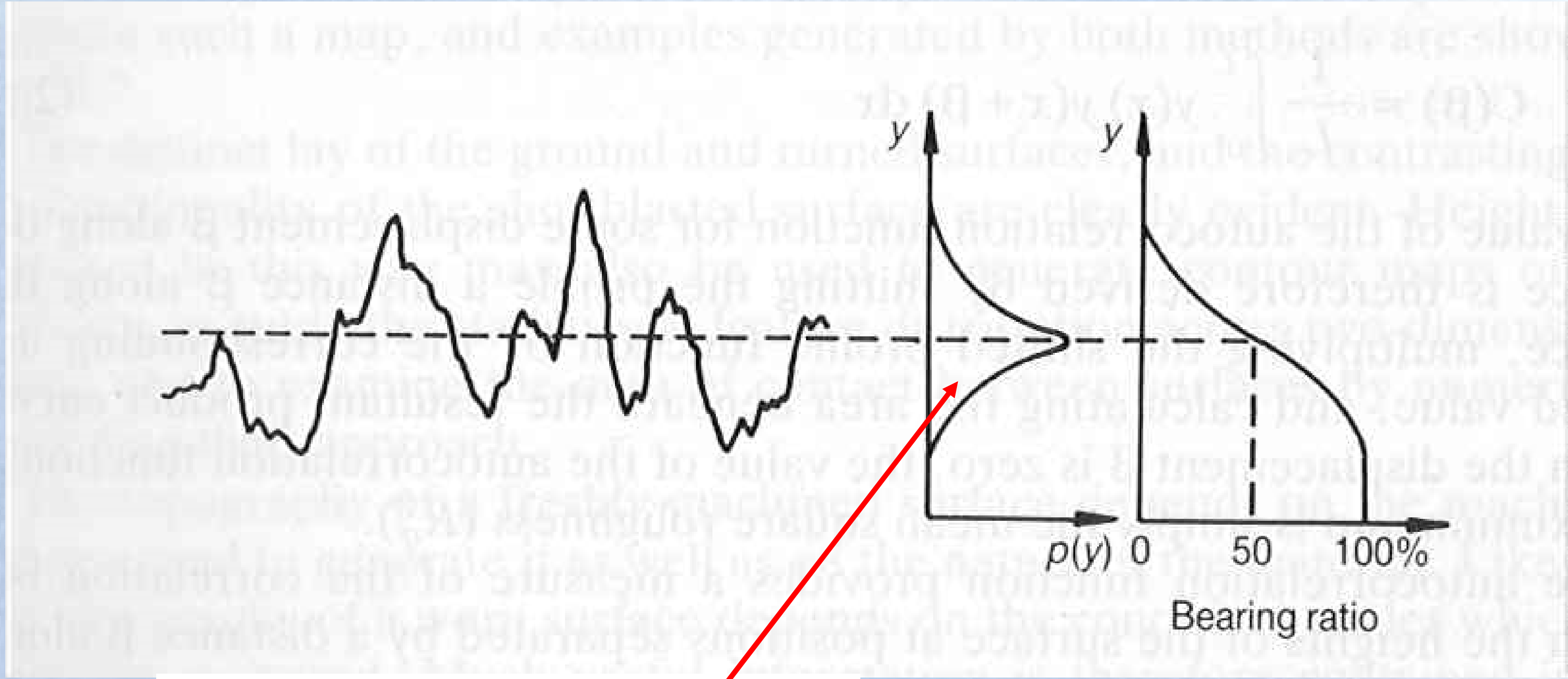
$$R_q = \sqrt{\frac{1}{L}\int_0^L y(x)^2\,dx}$$

- R.M.S slope, $\boldsymbol{\Delta_q}$:

$$\Delta_q = \sqrt{\frac{1}{L}\int_0^L \left(\theta(x) - \bar{\theta}\right)^2 dx} \qquad \bar{\theta} = \frac{1}{L}\int_0^L \theta(x)\,dx$$

The Amplitude Density Function

Describes the probability to find a point on the surface at height '*y*' above the mean line



(Gaussian distribution)

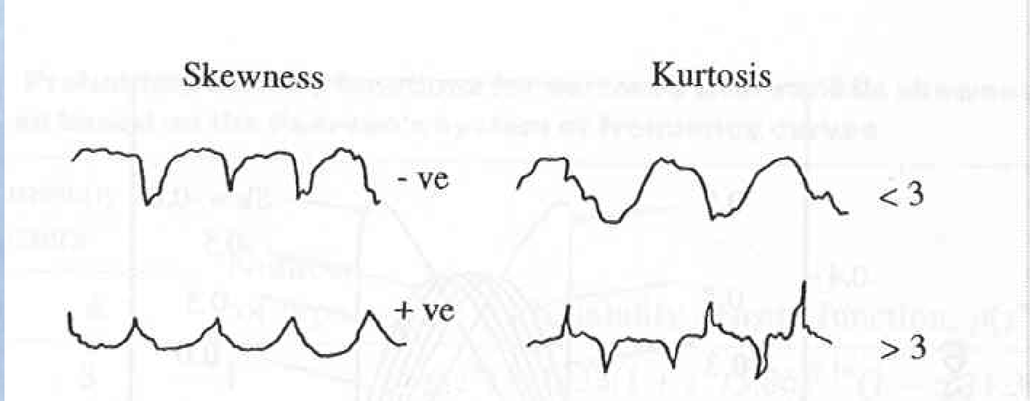
Skewness and Kurtosis

- Skewness is a measure of symmetry, or more precisely, the lack of symmetry. A distribution, or data set, is symmetric if it looks the same to the left and right of the center point.

- Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. That is, data sets with high kurtosis tend to have a distinct peak near the mean, decline rather rapidly, and have heavy tails. Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak. A uniform distribution would be the extreme case.

Skewness and Kurtosis

- Skewness, ***Sk***:
  - Describes the asymmetry from Gaussian of the amplitude density curve. ***Sk***=0 for Gaussian surfaces
- Kurtosis, ***K***:
  - Describes the peakedness. ***K***=3 for Gaussian surfaces and ***K***>3 for surfaces with more sharp peaks, ***K***<3 for less sharp peaks



$$Sk = \frac{1}{R_q^3 L} \int_0^L y(x)^3 \, dx$$

$$K = \frac{1}{R_q^4 L} \int_0^L y(x)^4 \, dx$$

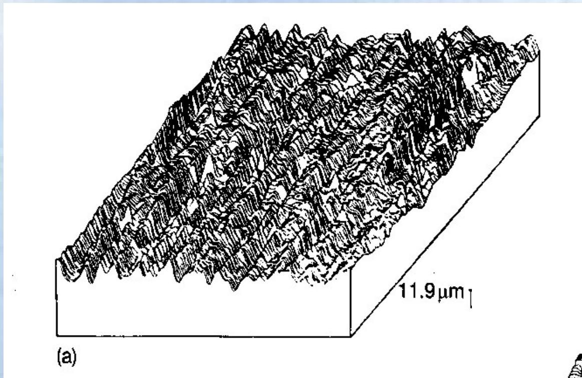
Auto-correlation function

$$C(\beta) = \frac{1}{L}\int_0^L y(x)y(x+\beta)dx$$

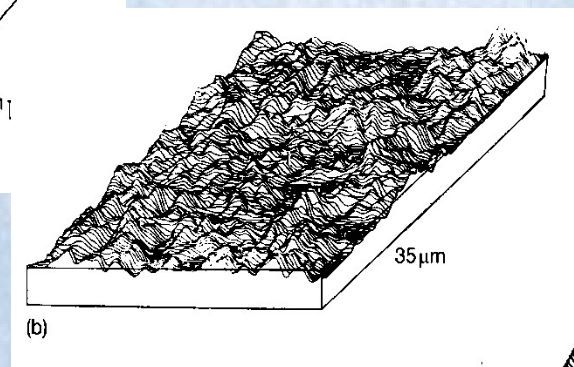
•Describes the occurance of any regular undulations of the surface

•Dominating wavelengths can be found

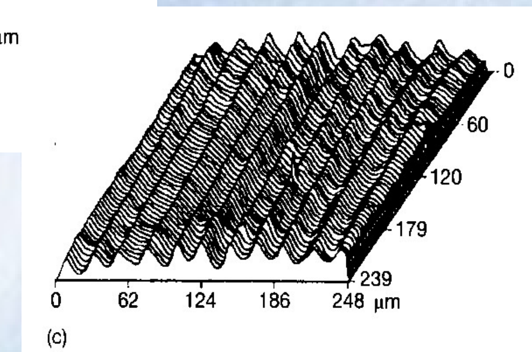
The topography of Engineering Surfaces



Ground steel surface

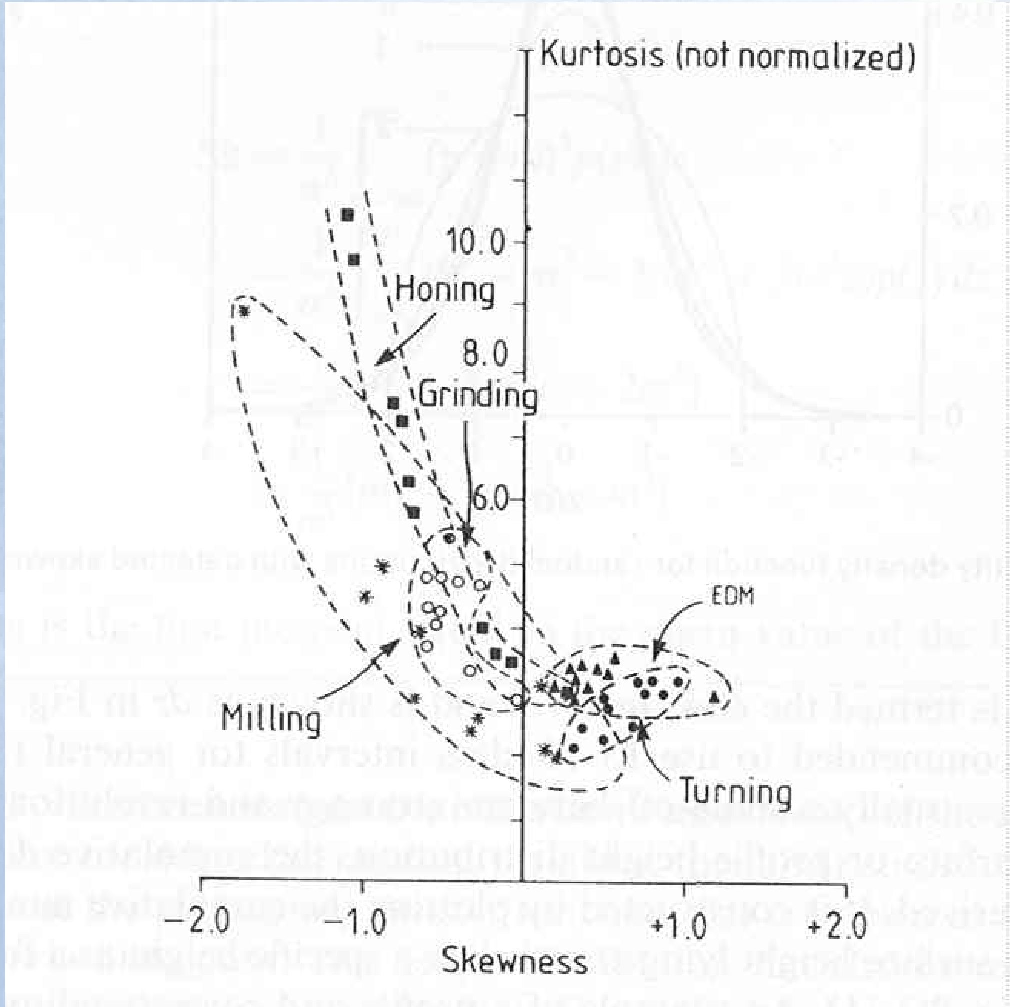


Shot-blasted steel surface



Diamond turned surface

Skewness and Kurtosis for Engineering Surfaces



Typical Ra values for Engineering Surfaces

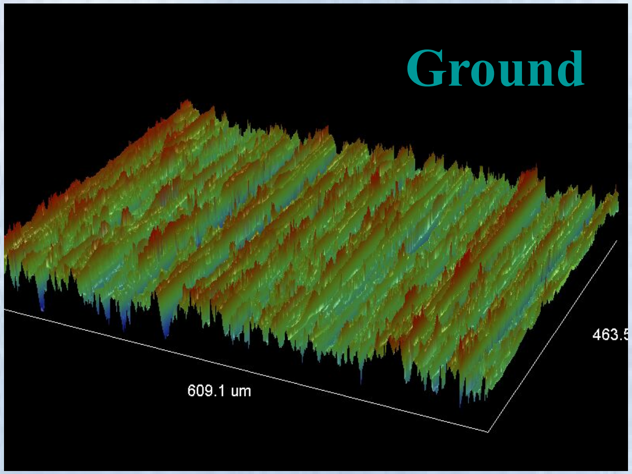
Process	Ra (μm)
Planing, shaping	*1-25*
Milling	*1-6*
Drawing, extrusion	*1-3*
Turning, boring	*0.4-6*
Grinding	*0.1-2*
Honing	*0.1-1*
Polishing	*0.1-0.4*
Lapping	*0.05-0.4*

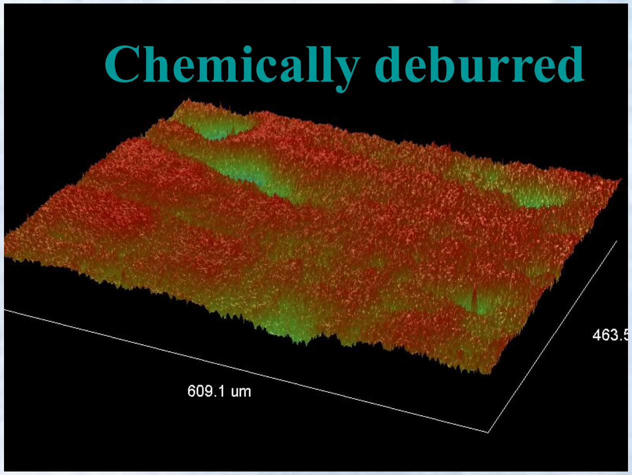
(I.M. Hutchings)

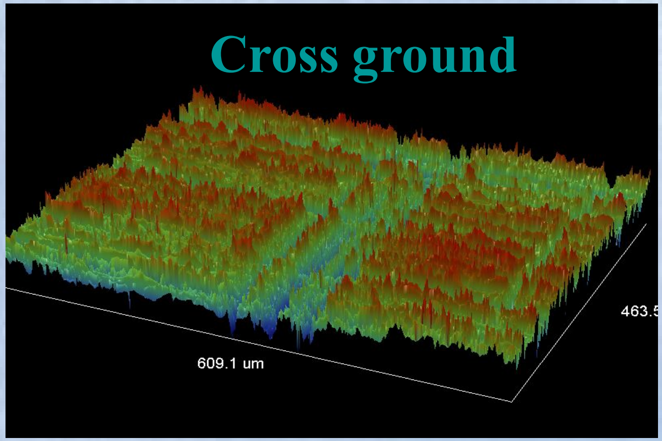
3D surface roughness parameters

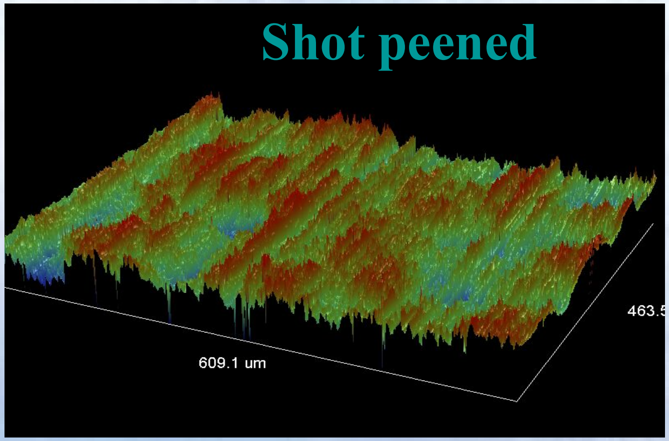
- Amplitude parameters
  - RMS deviation, ***Sq***
  - Skewness, ***Ssk***
  - Ten point height, ***Sz***
  - Kurtosis, ***Sku***
- Texture parameters
  - Density of summits, ***Sds***
  - Texture direction, ***Std***
  - Texture aspect ratio, ***Str***
  - Fastest decay autocorr. length, ***Sal***
- Hybrid parameters
  - RMS slope, ***S∆q***
  - Devloped area ratio, ***Sdr***
  - Mean summit curvature, ***Ssc***
- Functional parameters
  - Surface bearing index, ***Sbi***
  - Valley fluid retention index, ***Svi***
  - Core fluid retention index, ***Sci***

Surfaces Manufactured in Different Ways









Source: John Lord, LTU

Some Remarks about Surface Topography

- Surface topography plays an important role in determining the performance of various tribological machine components.
- There is a need to establish a correlation between surface topography and tribological performance in order to establish optimal surface topography specifications for different moving machine components.

As someone has said:

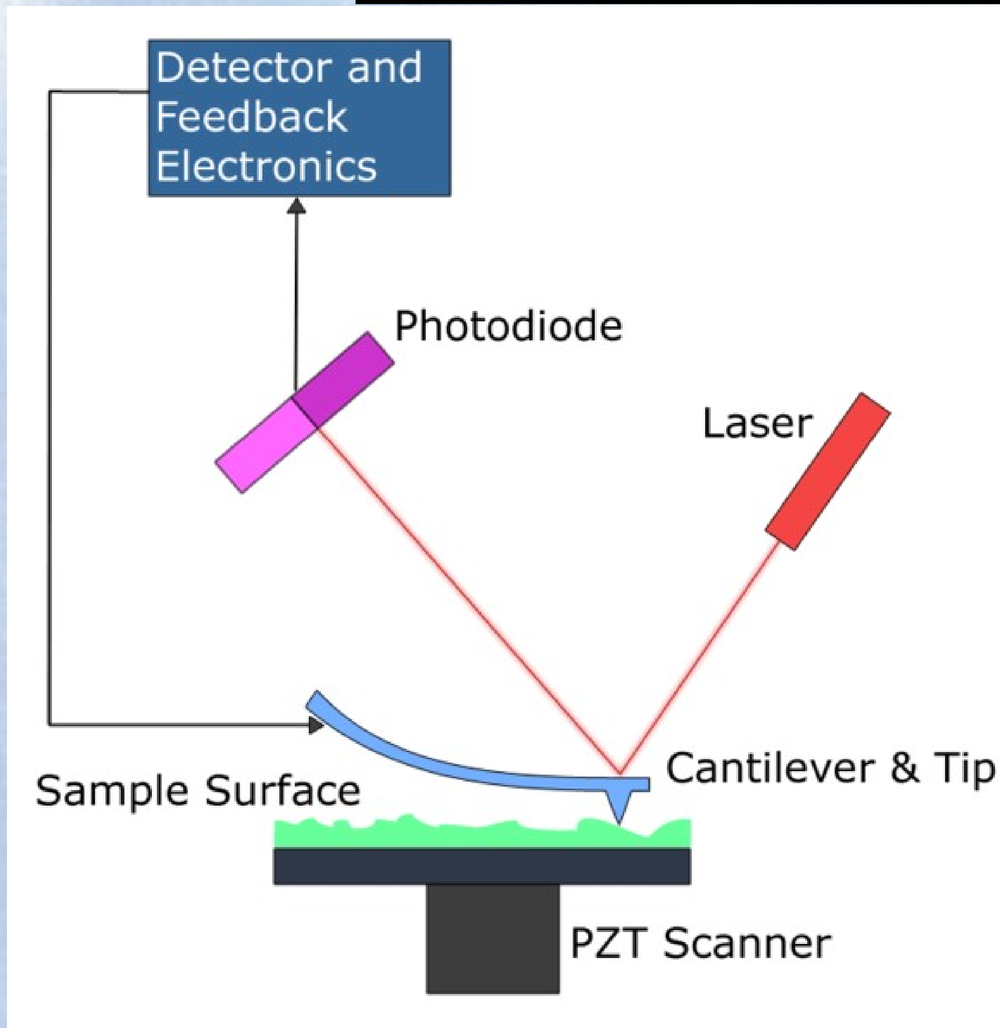
"The surfaces should be as smooth as possible but as rough as necessary".

It is, of course easier said than done.

Future challenges are to produce the surfaces having specified topographical parameters for optimal tribological performance.

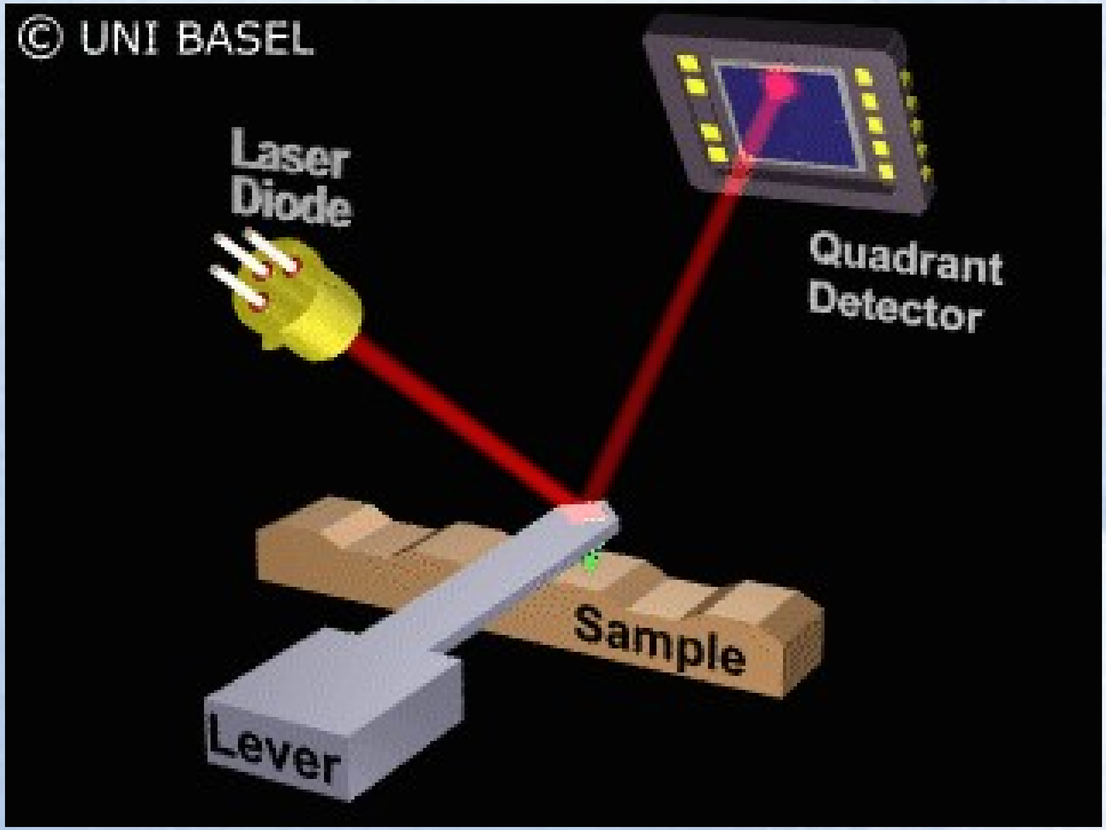
AFM

Invented by Gerd Bining and Heinrich Rohrer in the beginning of 80's; Nobel prize 1986



Atomic Force Microscope/Fluid Force Micro.

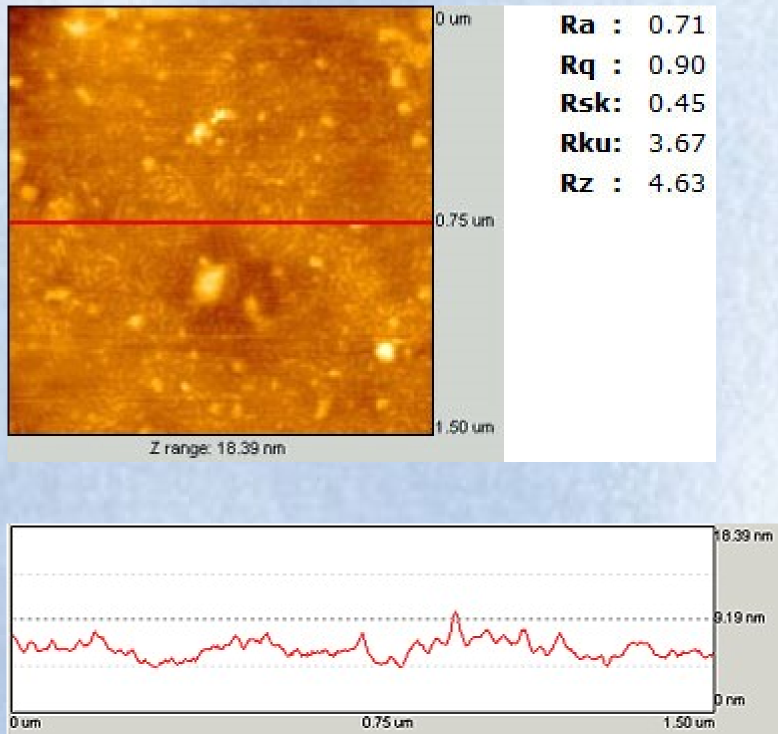
- Stiffness of the cantilever is known
- Torsional, lateral and normal deformation measured
- Forces can be obtained!



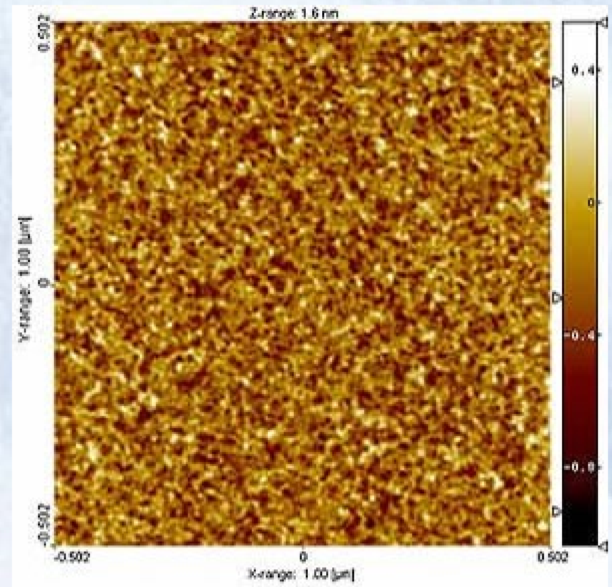
Some AFM Data

- Tip radius down to a few nm
- Spatial scan lengths, typically 100x100 nm to 10x10 μm
- Normal loads in the 1-100 nN range

Surface Roughness Reasured by AFM



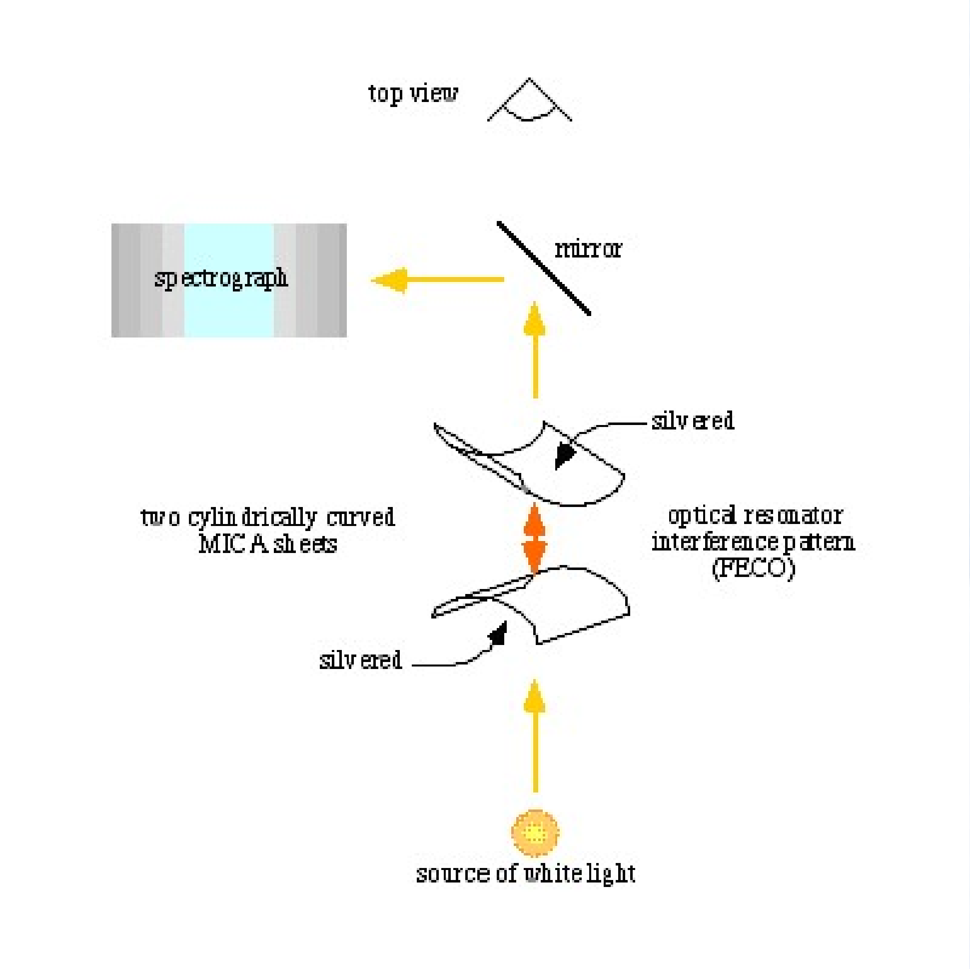
Surface roughness of a polymer film. 1.5 X 1.5 µm



1 µm X 1 µm image of a bare silicon wafer image

Surface Force Apparatus

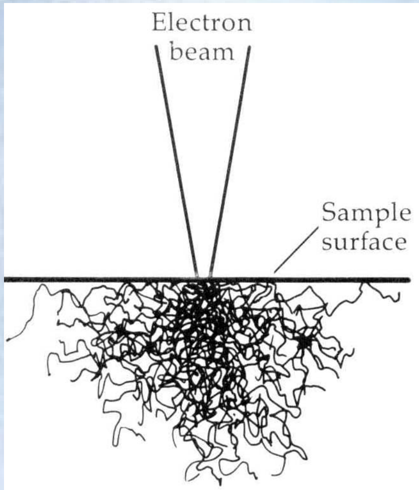
- Atomically smooth mica surfaces in circular point contact
- Optical interferometric measurement of distance between cylinders (film thickness)
- Applications:
  - Weak surface forces
  - Surface layer properties
  - Ultra thin film rheology

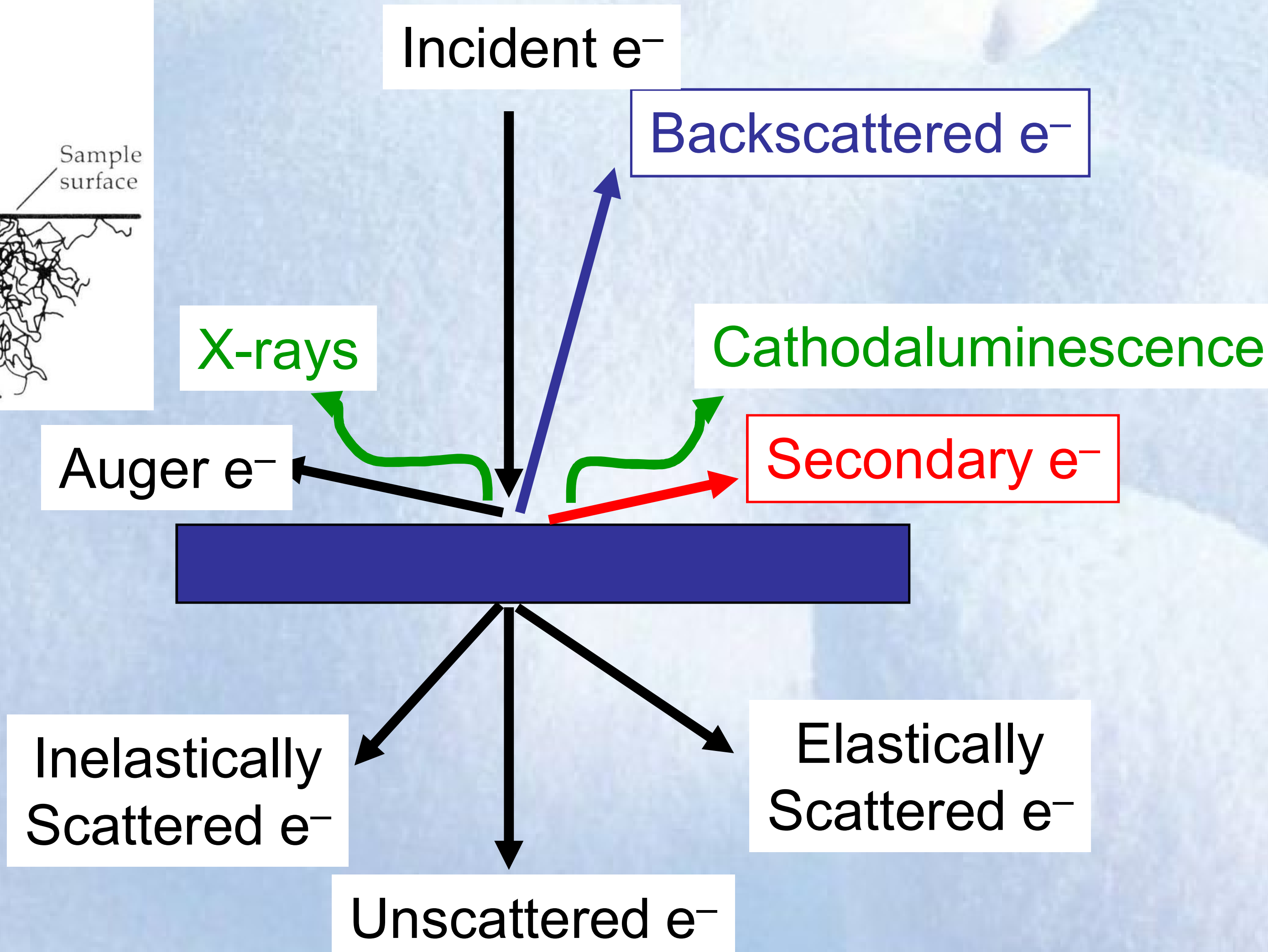


Techniques for Surface Chemistry

- SEM with Energy Absorption Spectroscopy
- or Wavelength Dispersive Spectroscopy ("microprobes")
  (few µm of surface)
- Scanning Auger Spectroscopy
  (few nm of surface)
- Secondary Ion Mass Spectroscopy
- (atomic layer by layer)
- X-ray photoelectron spectroscopy (XPS)
- and many more....

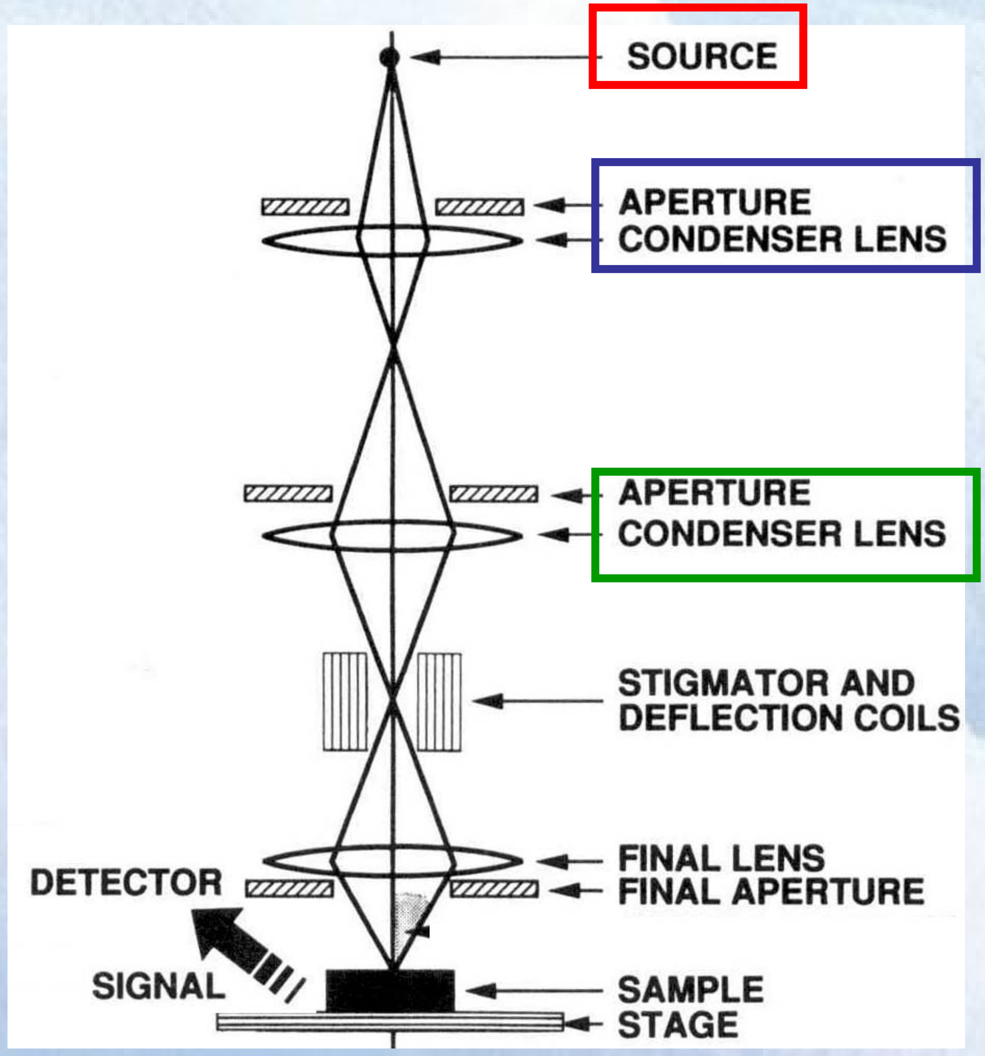
Electron Interactions





SEM Optics #1

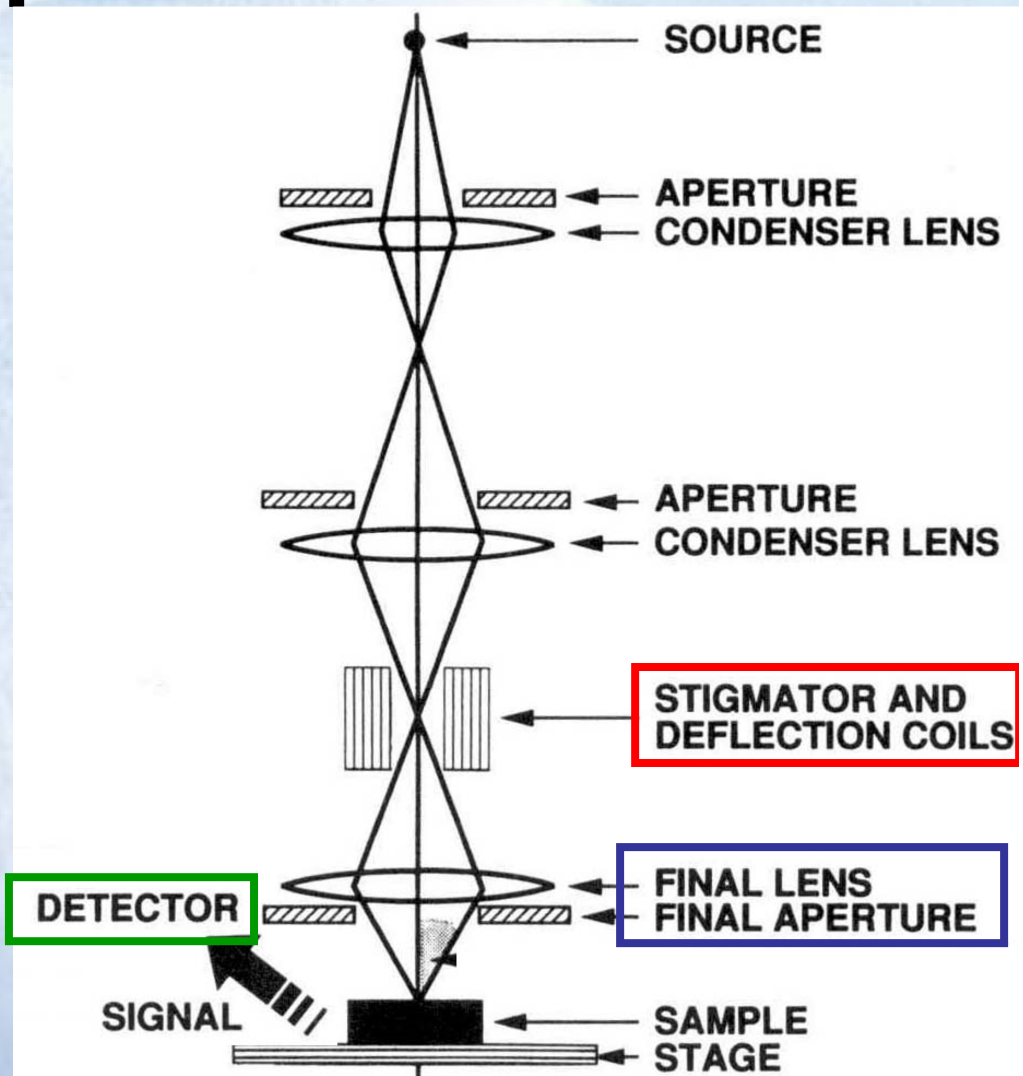
- Electron gun produces beam of monochromatic electrons.
- First condenser lens forms beam and limits current ("coarse knob").
- Condenser aperture eliminates high-angle electrons.
- Second condenser lens forms thinner, coherent beam (fine knob).
- Objective aperture (usu. user-selectable) further eliminates high-angle electrons from beam.



http://www.unl.edu/CMRAcfem/semoptic.htm

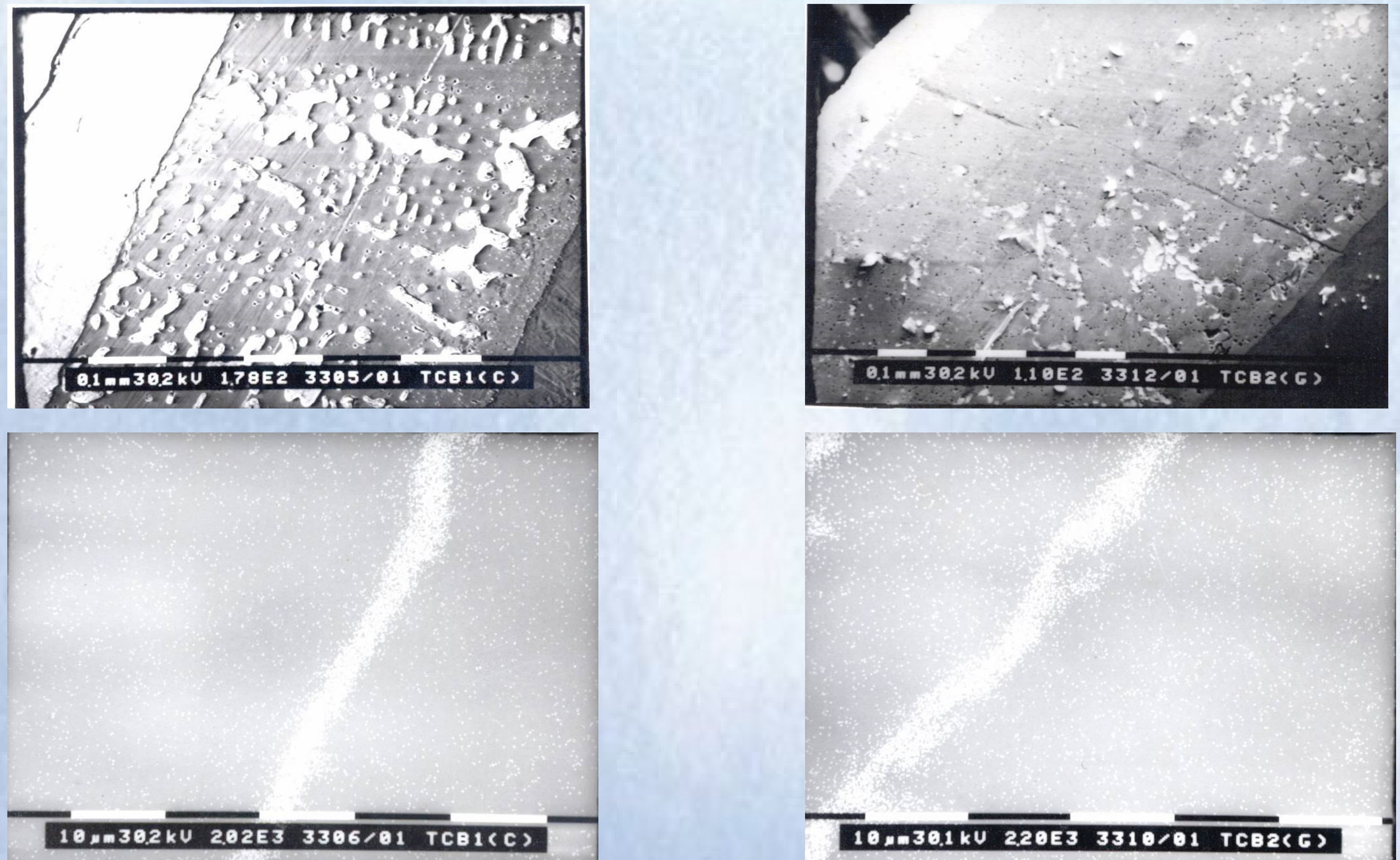
SEM Optics #2

- Beam "scanned" by deflection coils to form image.
- Final objective lens focuses beam onto specimen.
- Beam interacts with sample and outgoing electrons are detected.
- Detector counts electrons at given location and displays intensity.
- Process repeated until scan is finished (usu. 30 frames/sec).



http://www.unl.edu/CMRAcfem/semoptic.htm

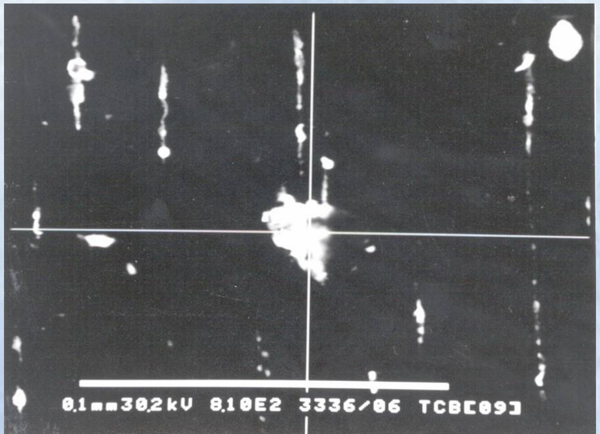
Some Examples of SEM/EDS Analysis

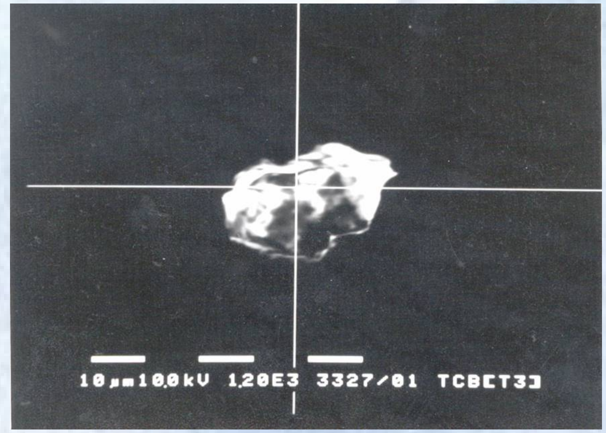


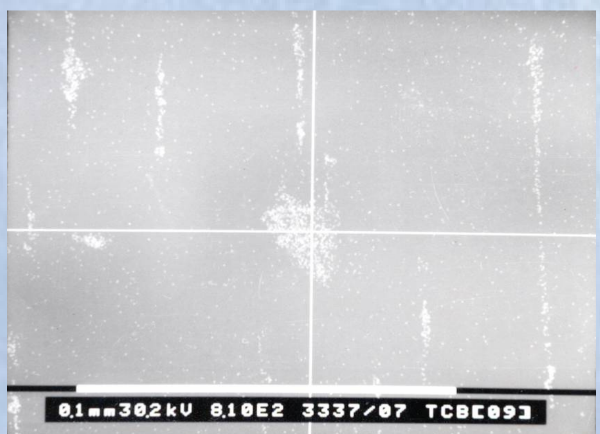
Microstructure and Ni barrier of engine bearings from two suppliers

SEM Micrograph Showing Si Particles Embedded on a Crankshaft Bearing Surface

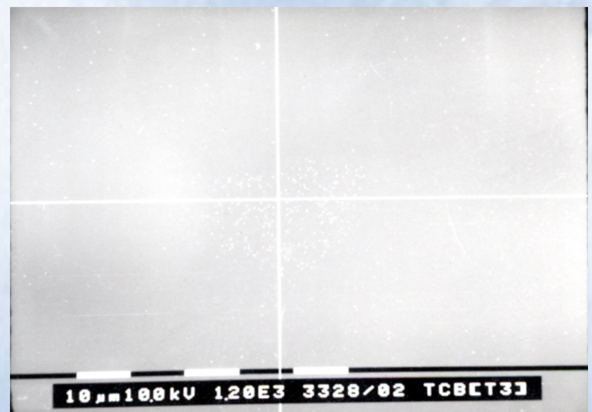
SEM Ferrogram and X-Ray Dot Mapping







Fe particles



Si particles

Some Examples of Scanning Auger Microscopy

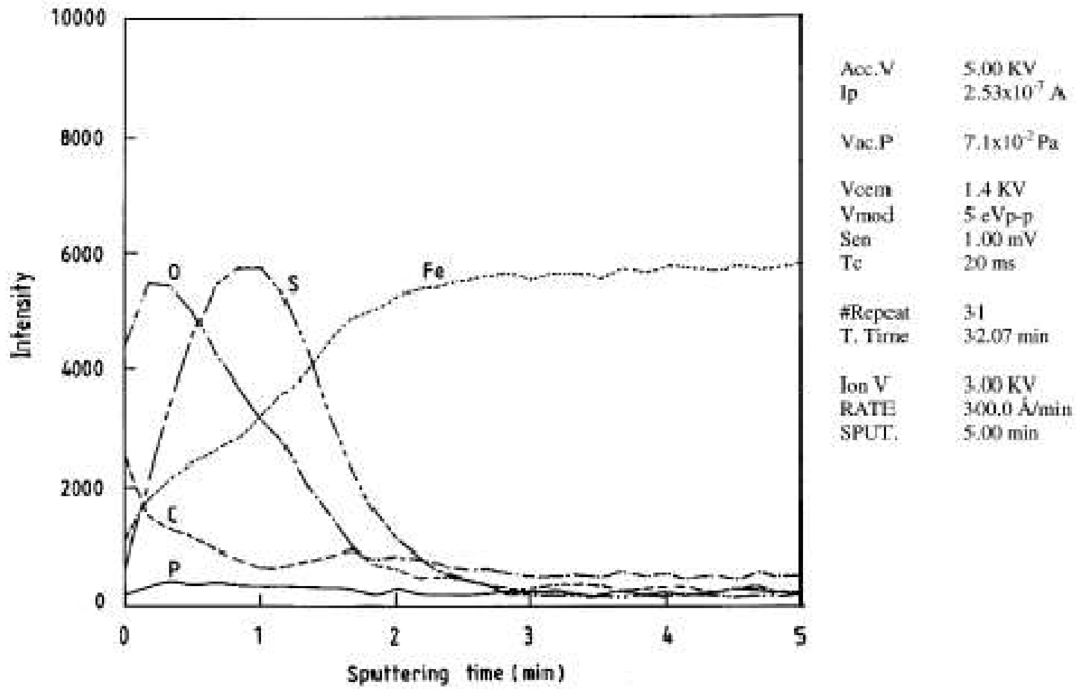


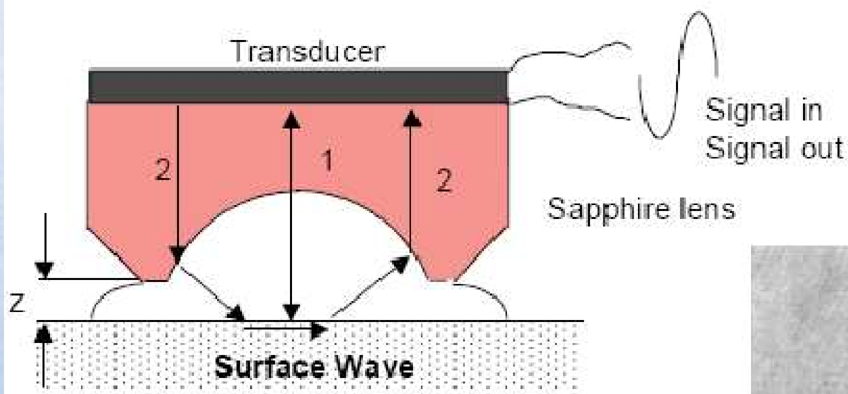
Fig. 7. Auger spectrum from worn scar under operating conditions: 20 N load, 0.75 μm roughness and 50 °C temperature.

A systematic methodology to characterise the running-in and steady-state wear processes
Wear, Volume 252, Issues 5-6, March 2002, Pages 445-453
Rajesh Kumar, Braham Prakash and A. Sethuramiah

Techniques for Detecting Cracks

- Visual” methods
- Dye- penetrant
- SEM / TEM
- X-ray
- Acoustic methods
- Ultrasonics
- Acoustic microscopy
- Electro-magnetic methods
- Eddy Current
- Magnetic Particle Inspection

Acoustic Microscopy

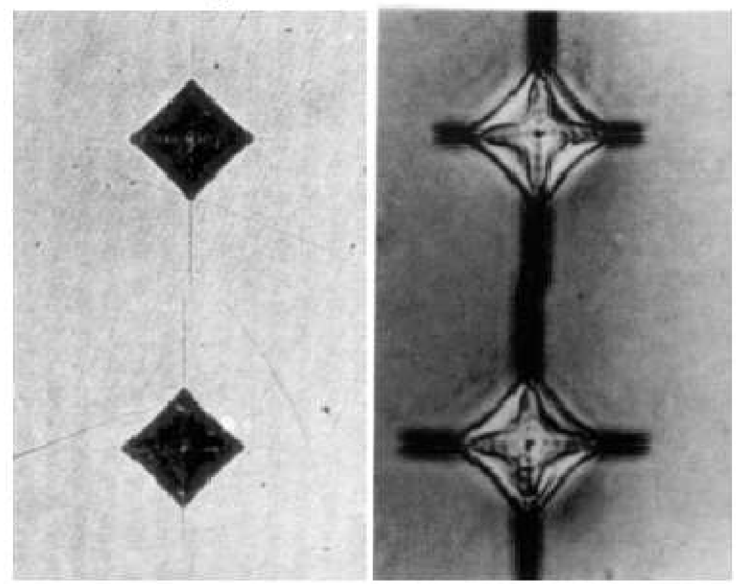


Acoustic lens is scanned over surface – signal is injected via water drop and collected.

Interference between "reflected wave" (1) & Surface wave (2) controls signal out.

Any discontinuity in the surface that affects surface wave shows up strongly on image generated from signal out.

Indentation Cracks in zirconia:
Optical Acoustic



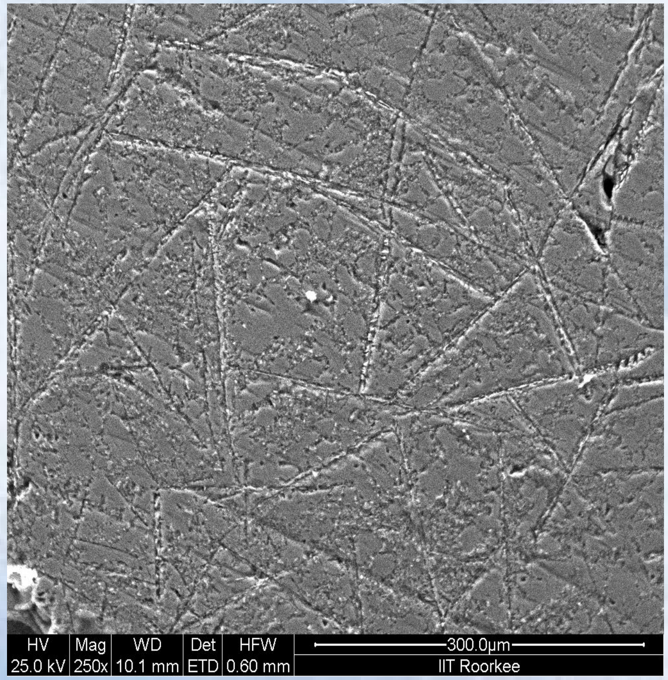
http://www.tms.org/pubs/journals/JOM/9811/Connor/Connor-9811.htm
"Acoustic microscopy", G.A.D. Briggs, Materials Library 32 BRII

Metallography

Metallography is the science and art of preparing a metal surface for analysis by **grinding**, **polishing**, and **etching** to show microstructural component.

Microstructure:

- Is the geometric arrangement of grains and the different phases present in a material.
- Study and characterization of materials.
- Ensure that the associations between properties and structure are properly understood.
- Predict properties of materials

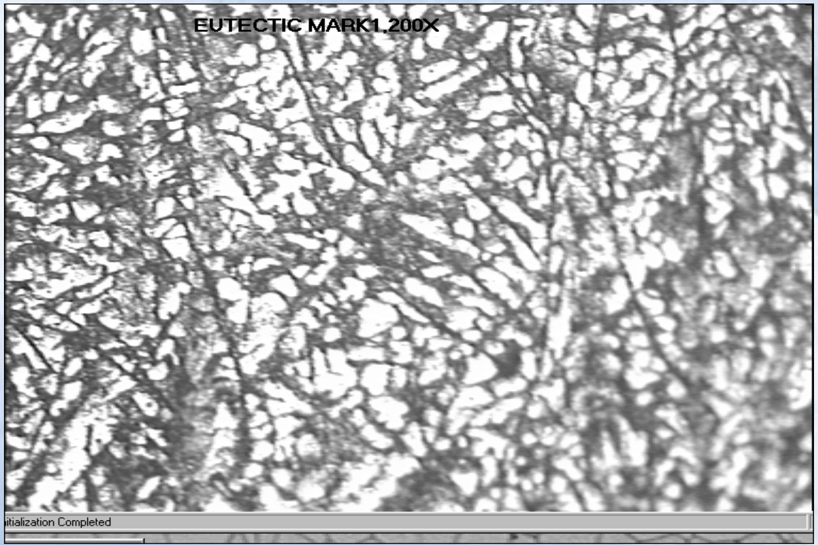


METHODS

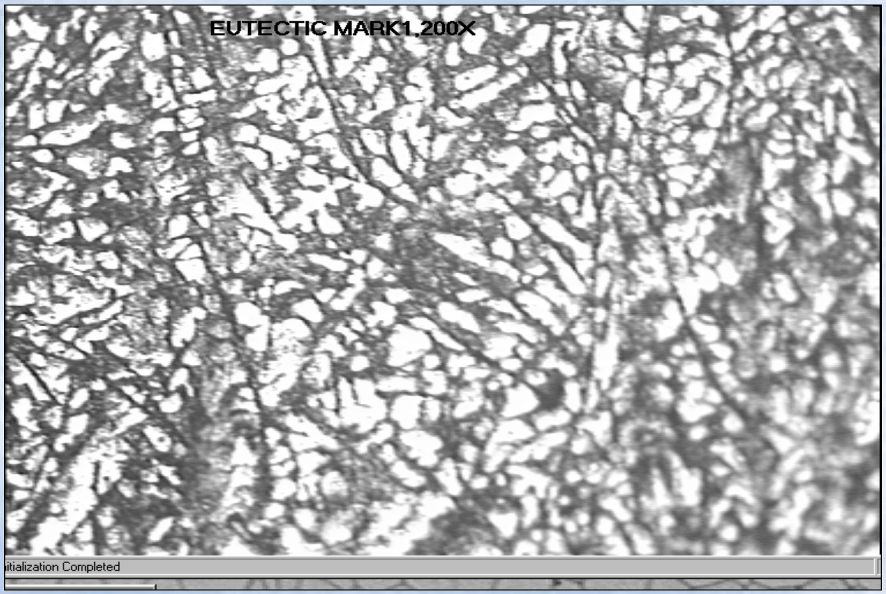
Sophisticated microstructure examination Involves, high powered instruments like,

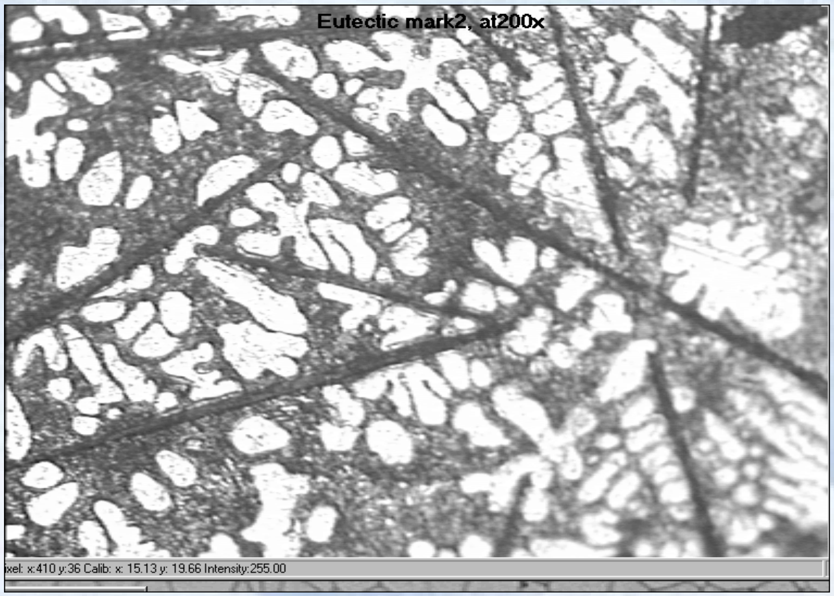
- Optical Microscopy
- Scanning Electron Microscopy (SEM)
- Energy dispersive- X-ray (EDEX)
- X-ray diffraction (XRD)

- **OPTICAL MICROSTRUCTURE**
  Al-12Si-0.5 Mg -1.2 (Conventional Cast)



OPTICAL MICROSTRUCTURE





Al-12Si-0.5 Mg -1.2 (Conventional Cast)

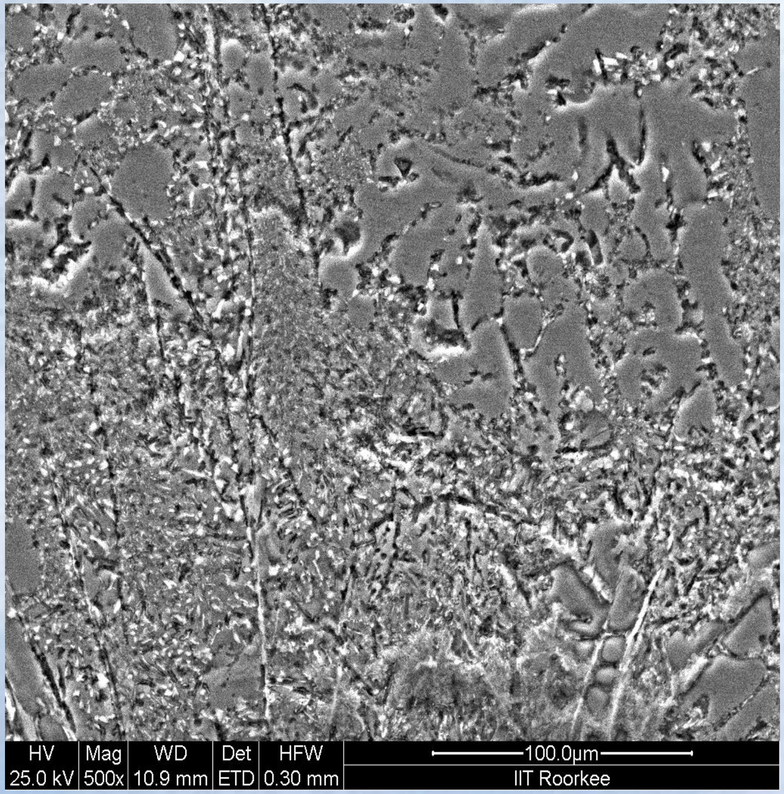
Al-12Si-0.5 Mg -1.2 Fe (Stir Cast)

OPTICAL MICROSTRUCTURE

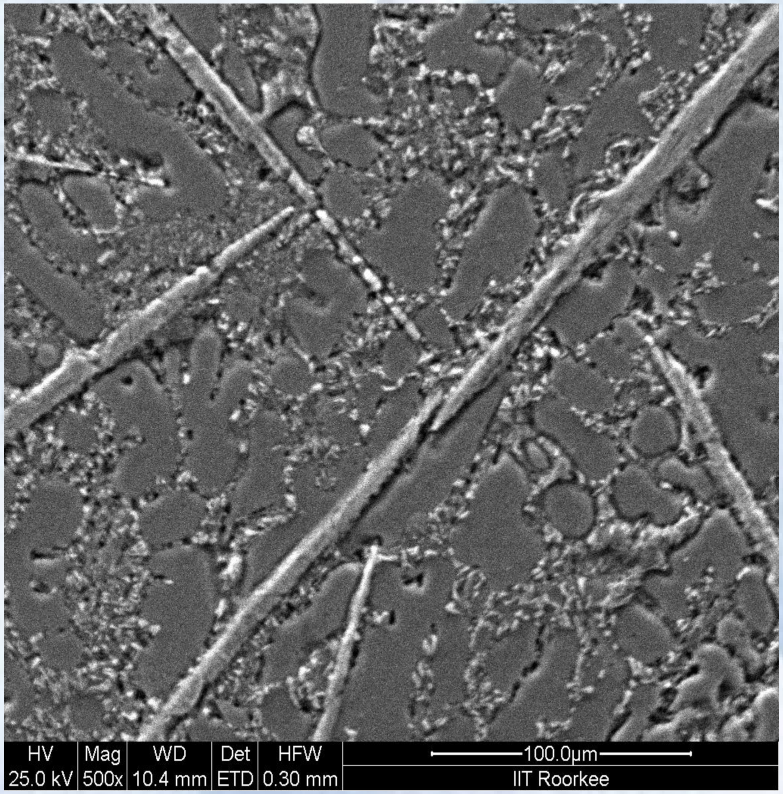
Al-20Si-0.5Mg-1.2Fe stir cast

Al-20Si-0.5Mg-1.2Fe-0.03 Be stir cast

SCANNING ELECTRON MICROSCOPY

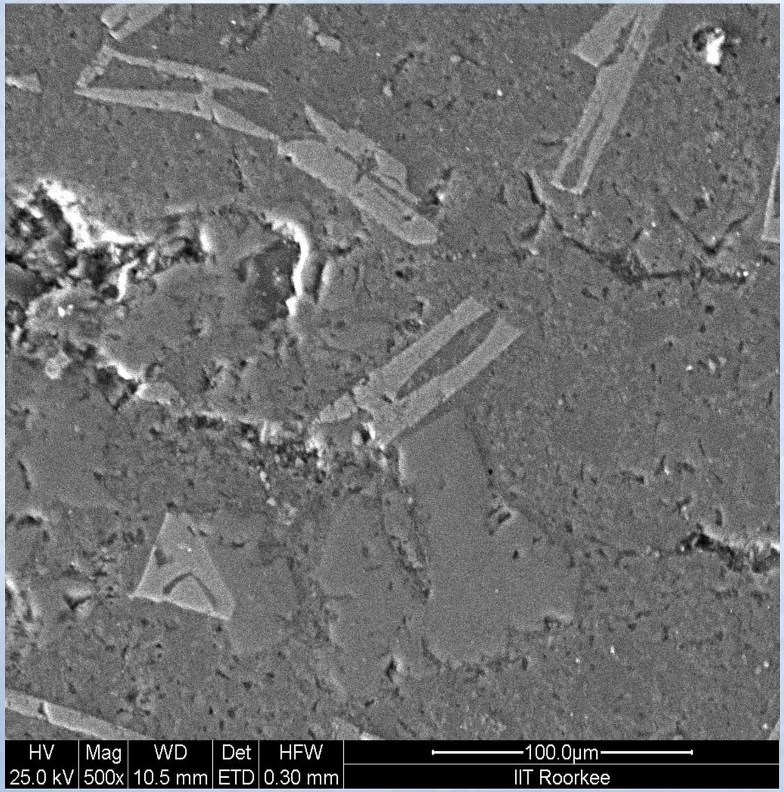


Al-12Si-0.5 Mg -1.2 Fe (conventional Cast)

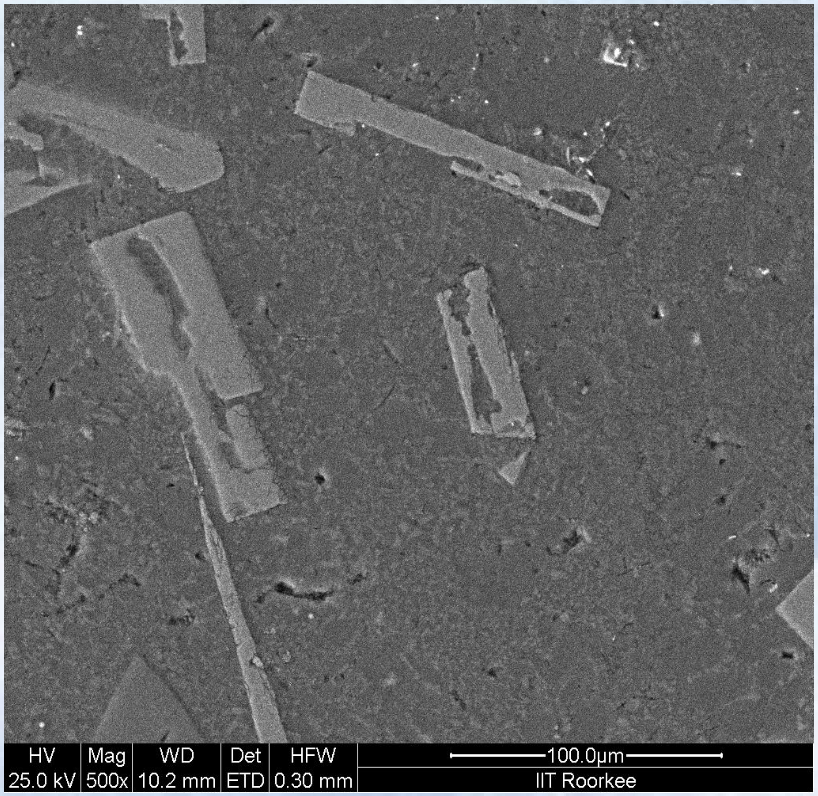


Al-12Si-0.5 Mg -1.2 Fe (Stir Cast)

SCANNING ELECTRON MICROSCOPY



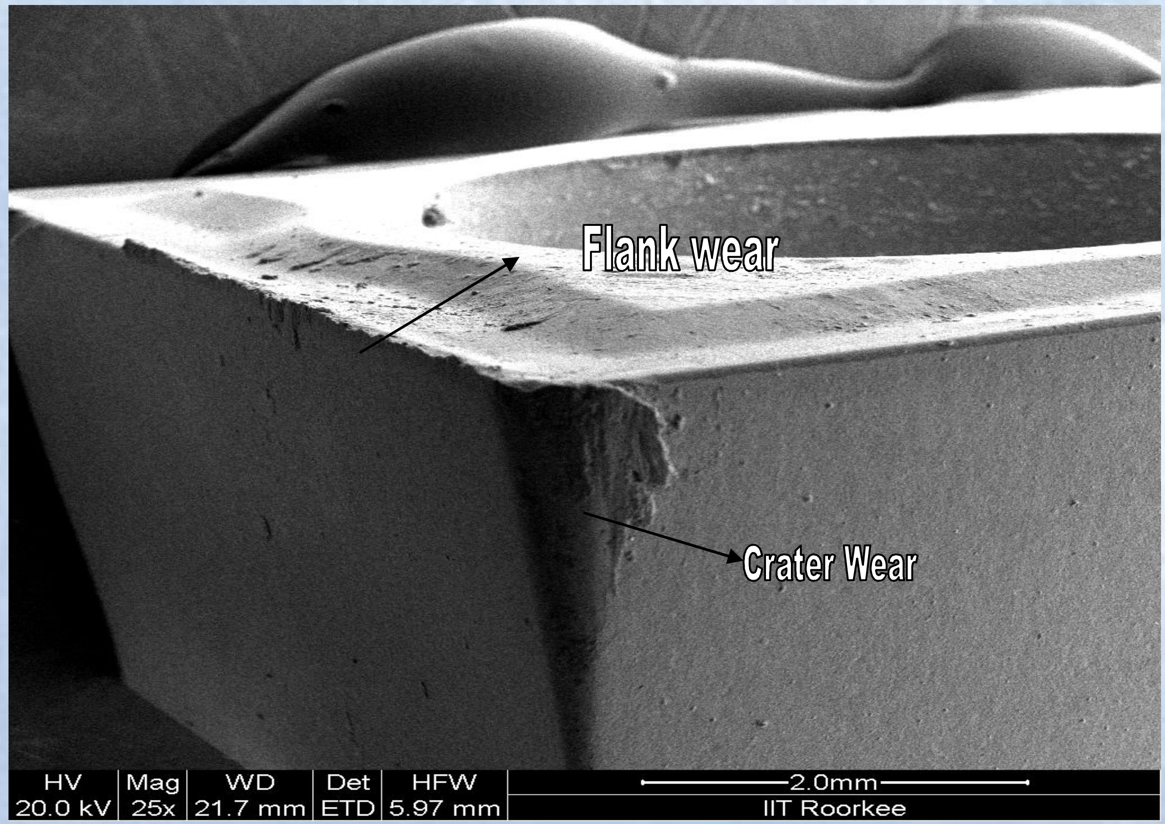
Al-20Si-0.5 Mg -1.2 Fe (Stir Cast)



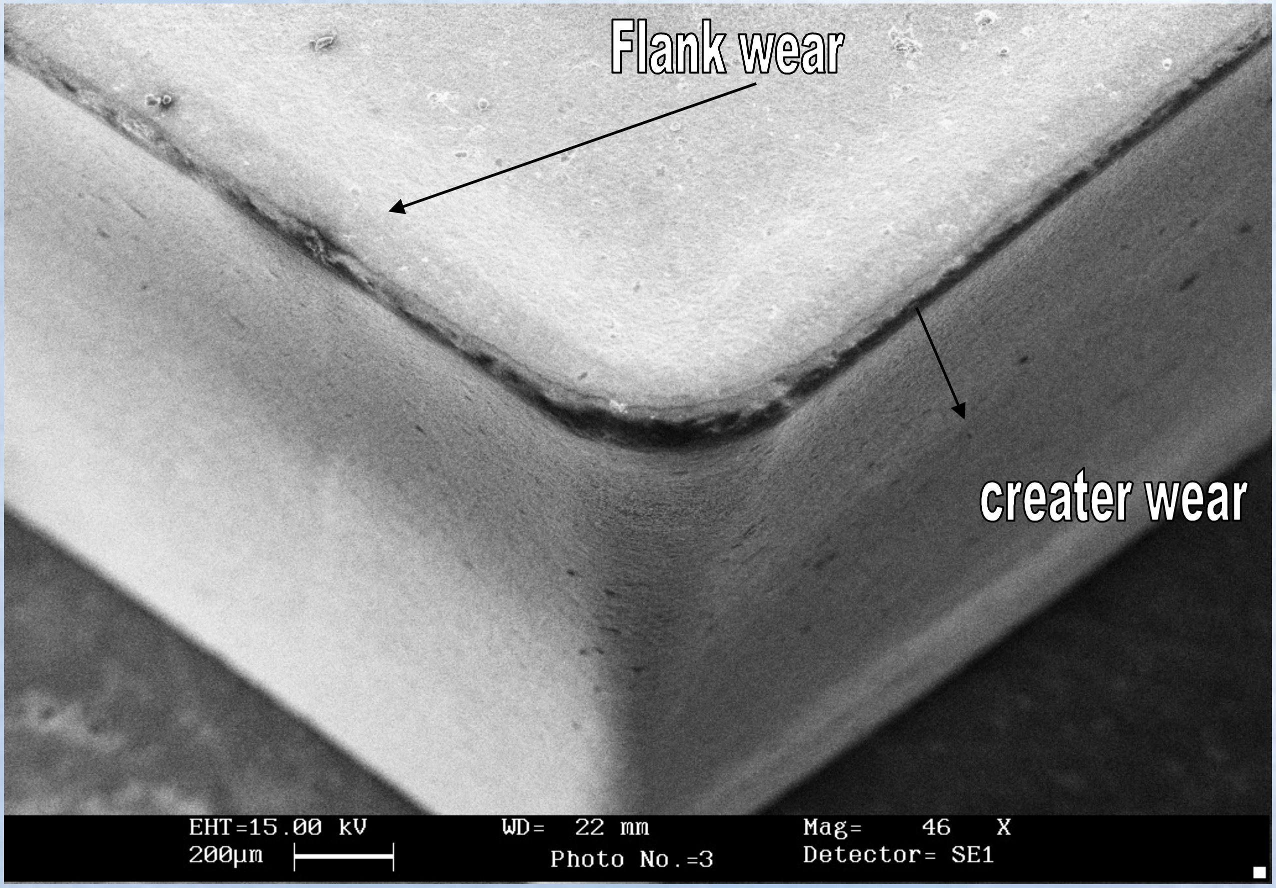
Al-20Si-0.5 Mg -1.2 Fe-0.03 Be (Stir Cast)

SEM image of tool wear Al-20 Si-0.5 Mg -1.2Fe (Stir Cast)

(cutting speed (150 m/min), feed rate(0.3mm/rev) depth of cut (1.0 mm) and A. angle (60°)]

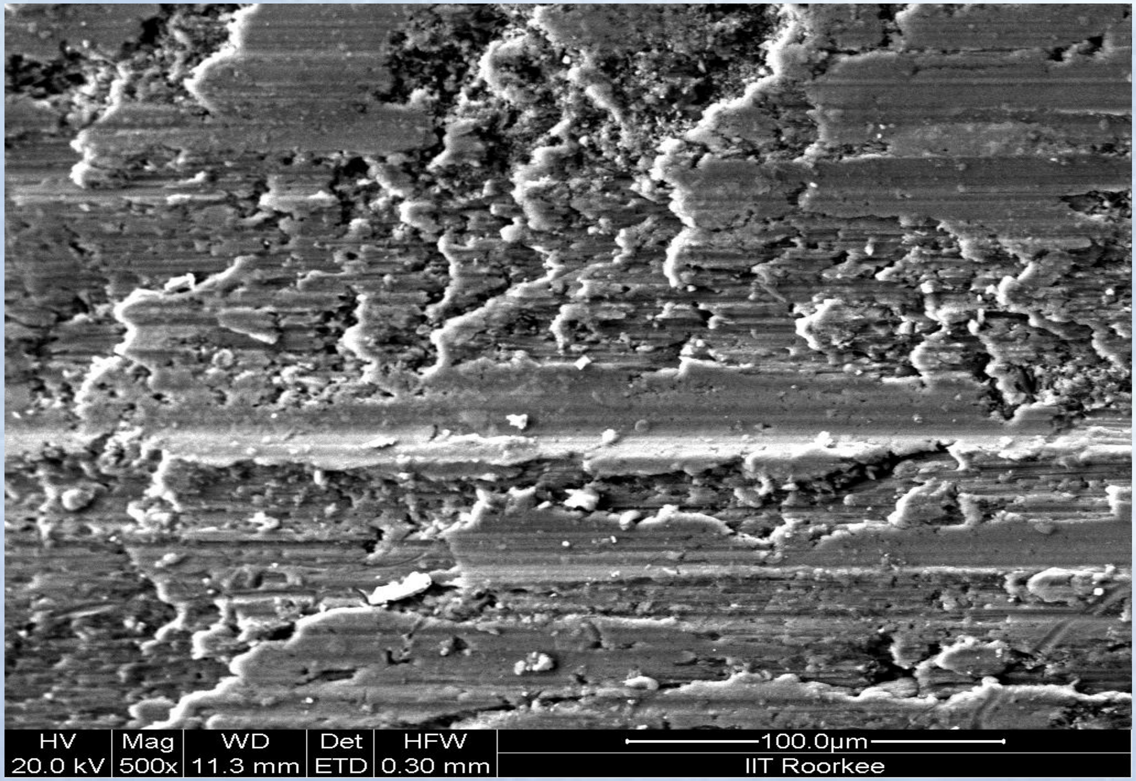


SEM Image of Tool wear Al-20 Si-0.5 Mg -1.2Fe -0.03 Be (Stir Cast) Cutting Speed(175m/min), Feed Rate (0.2 mm/rev), Depth of cut (2.0 mm) and A. Angle (45°)

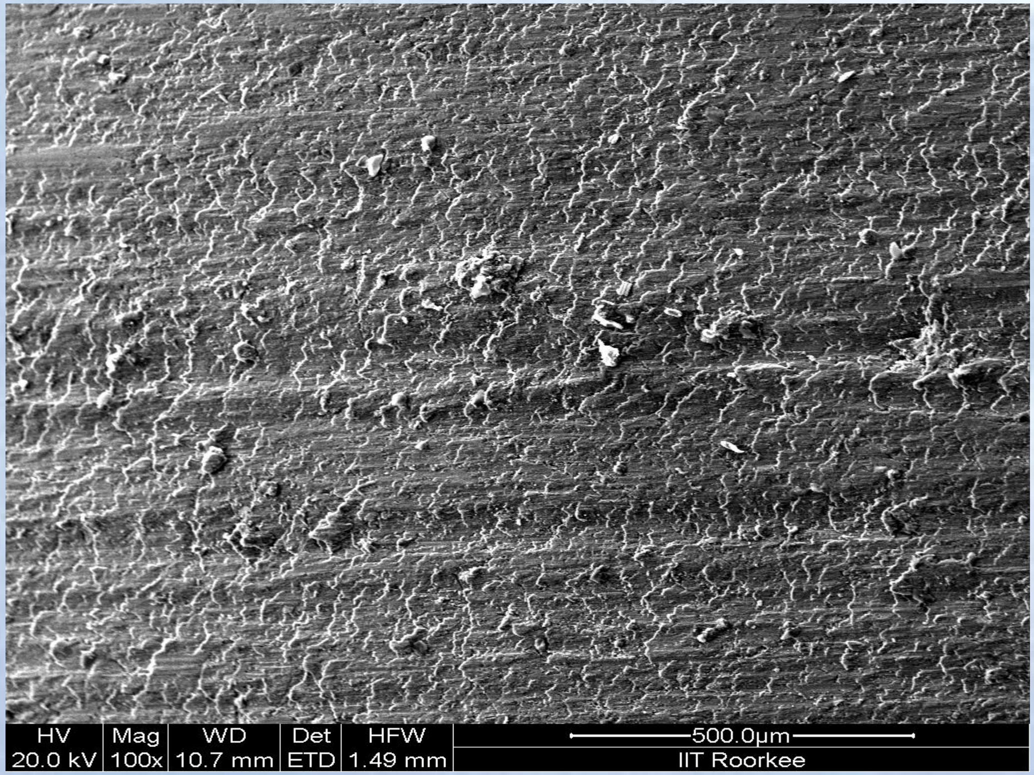


SEM image of Machined surface Al-20 Si-0.5 Mg -1.2Fe (Stir Cast)

[(cutting speed (150m/min), feed rate(0.3mm/rev) depth of cut (1.0 mm) and A. angle (60°)]

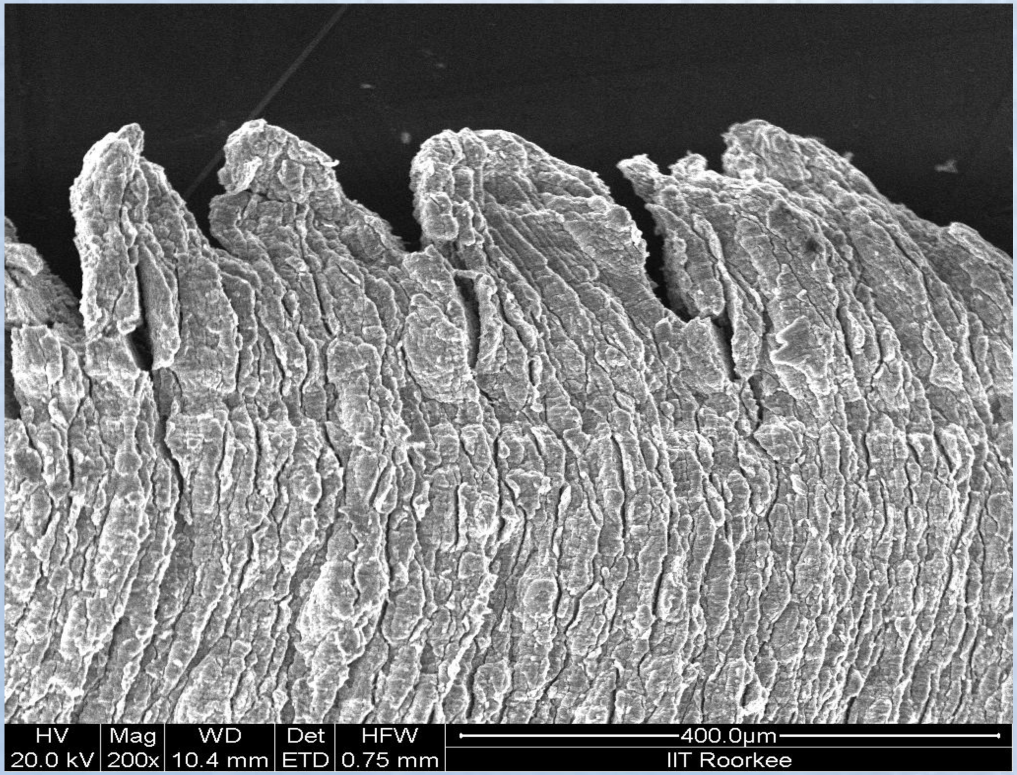


SEM image of Machined Surface
Al-20 Si-0.5 Mg -1.2Fe -0.03 Be (Stir Cast)
[cutting speed (175m/min), Feed rate (0.2 mm/rev), Depth of cut (2.0 mm) and A. angle (45°)]



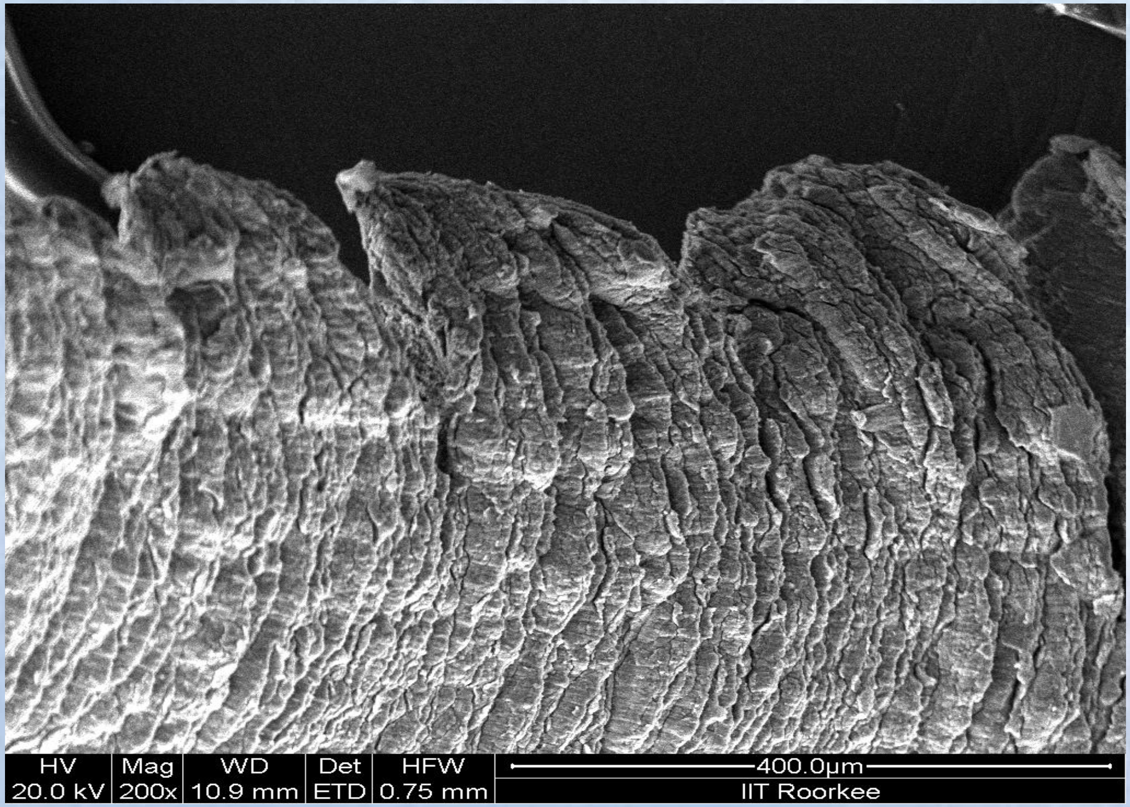
SEM image of a saw toothed chip
Al-20 Si-0.5 Mg -1.2Fe (Stir Cast)

(Cutting Speed (150 m/min), Feed Rate(0.3mm/rev), Depth of cut (1.0 mm) and A. Angle (60°)

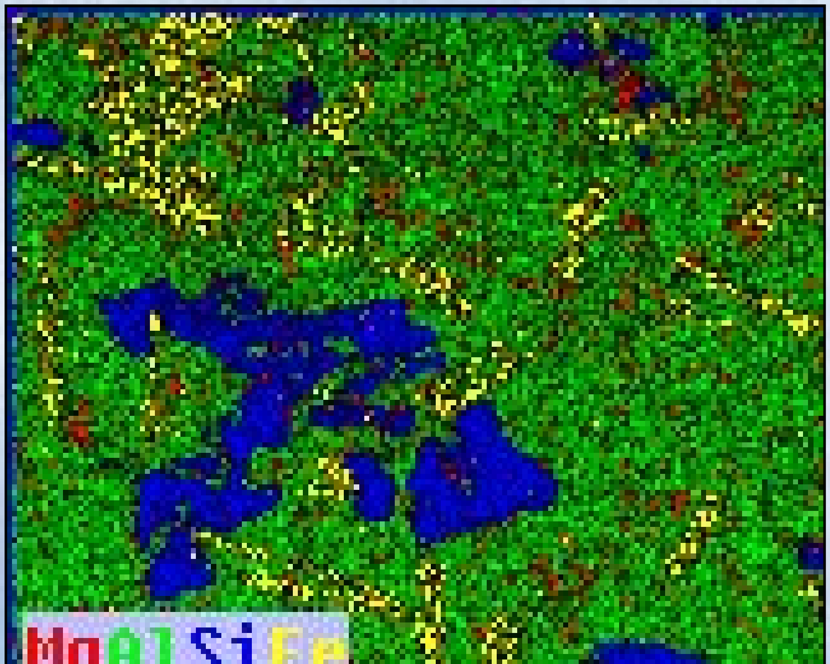


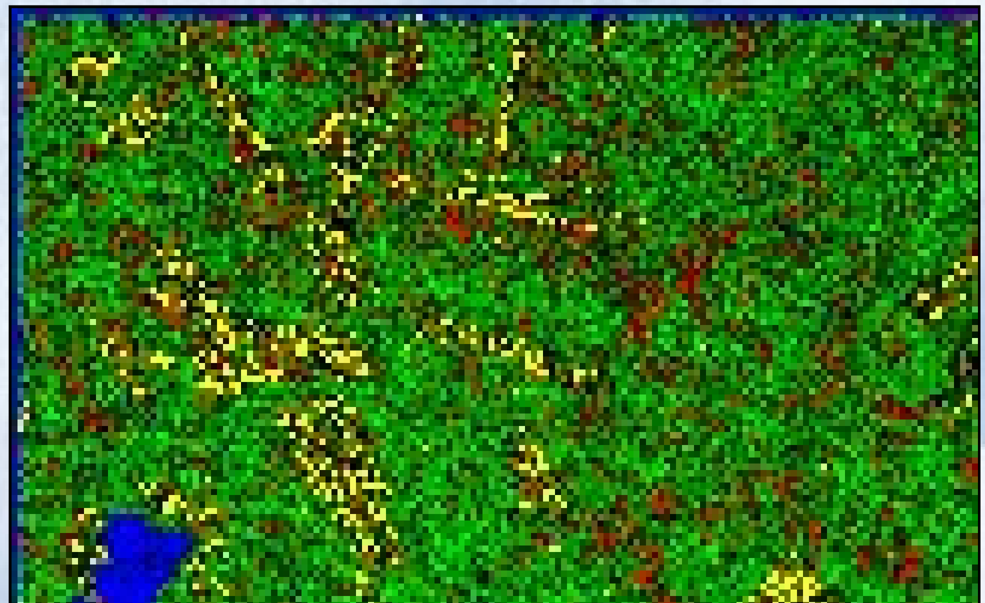
SEM Image of a Saw Toothed Chip
Al-20 Si-0.5 Mg -1.2Fe -0.03 Be (Stir Cast)

(Cutting speed(175m/min), Feed rate (0.2 mm/rev), Depth of Cut (2.0 mm) and A. Angle (45°)



Micro-analysis (Elemental Mapping)

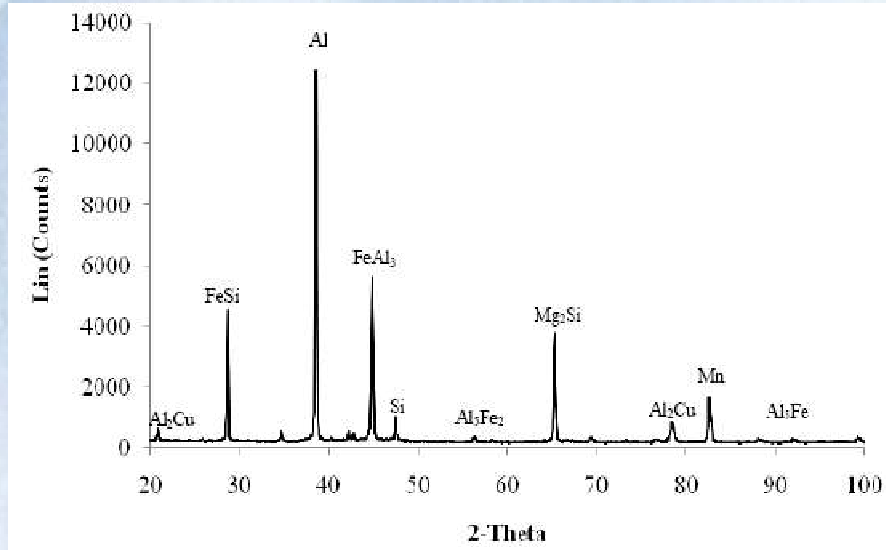




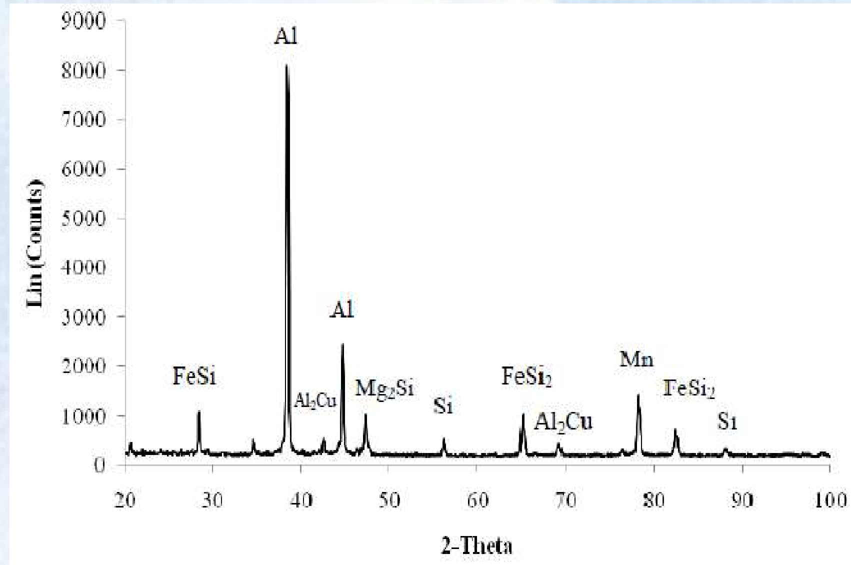
Al-20 Si-0.5 Mg -1.2Fe (Stir Cast)

Al-20 Si-0.5 Mg -1.2Fe -0.03 Be (Stir Cast)

XRD-Analysis



(a)



(b)

X-Ray Diffraction pattern of Al-18Si-4Cu-0.5Mg alloy with (a) 0.4 wt.% Fe, and (b) 2.0 wt.% Fe.

CONCLUSION

- The effect of stirring on the Al-12Si-0.5 Mg -1.2 Fe alloy can be seen from slide 4&5 in which the eutectic silicon is broken in to smaller shape and needles shape & size is also visible .
- The stir-cast process is known to control the morphology and size of the primary α –phase.
- The modification process is known to alter the morphology and fineness of the eutectic silicon
- Be addition changes the shape of iron rich compound from needle or plate shape to Chinese scripts or polygons.

CONCLUSION

- From the SEM images of tool wear, machined surface and saw toothed chips ,it is evident that Be addition has alter the morphology and fineness of the eutectic silicon which leads to improvement in mechanical properties and hence machinability in terms of tool wear, quality of machined surface and type of chip formed.

  The effect of modification can also be seen from the elemental mapping of the alloy, which clearly shows the proper distribution of elements after Be addition .

Thank You