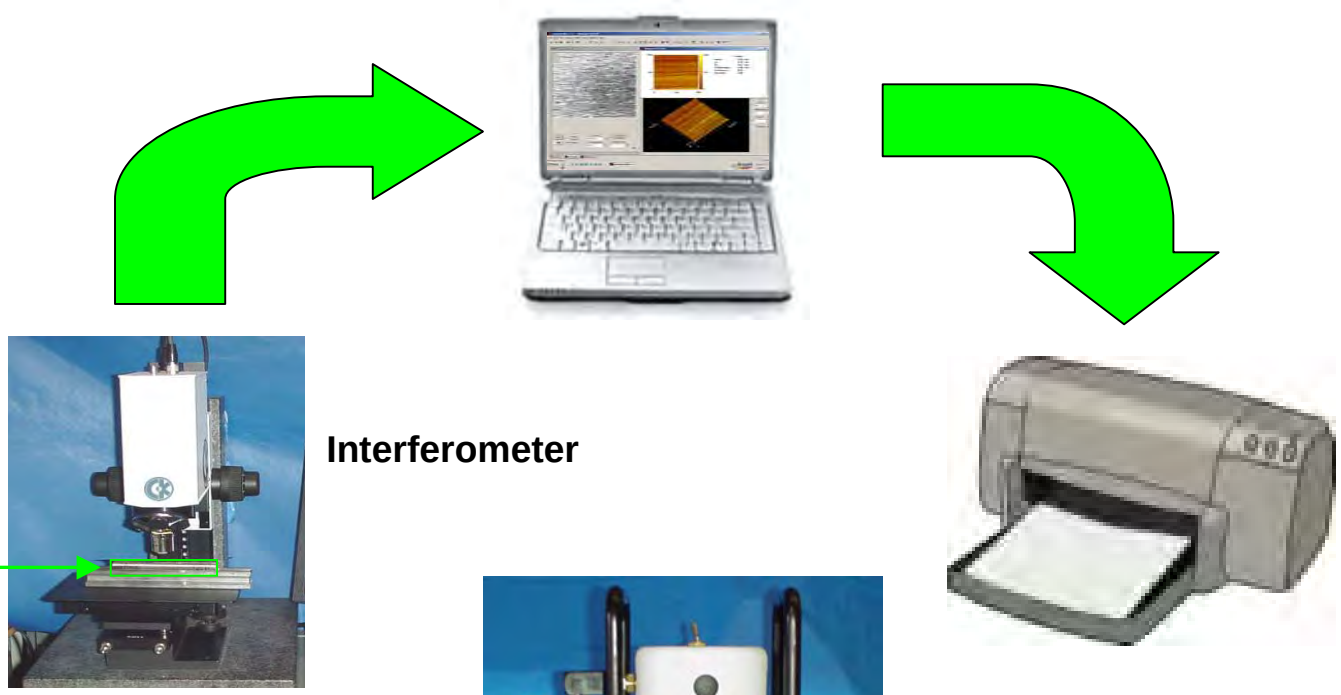
SEE 3-D

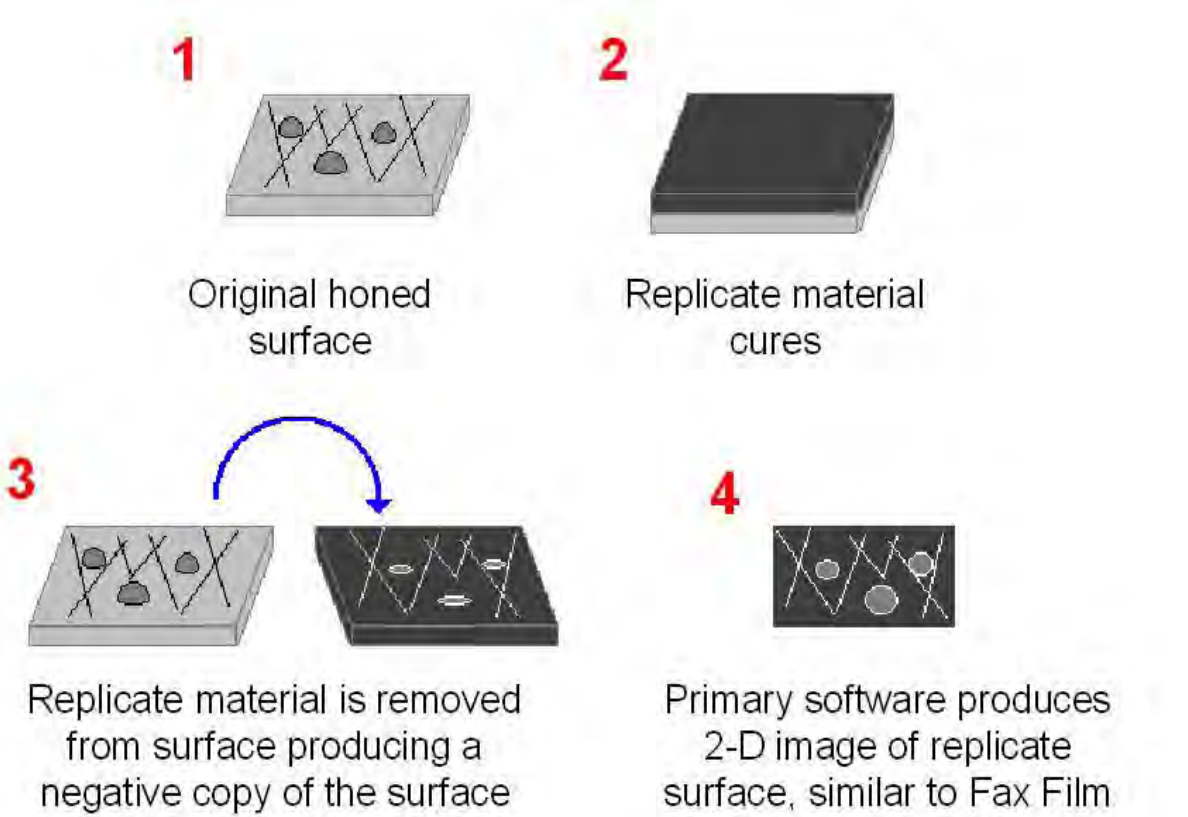
Surface Evaluation Equipment

C-K Engineering, Inc.

SEE 3-D System Components



Replication Process

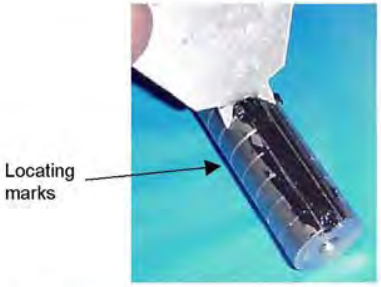


5 3-D software utilized provides applicable surface data and images

Steps in Making Replicate and Acquiring Data

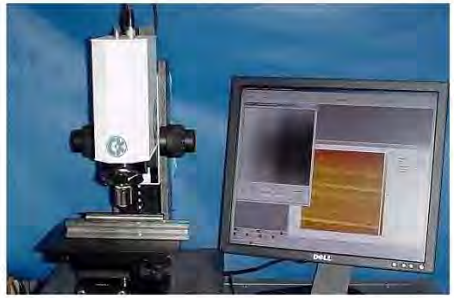
1. Clean specimen surface with lint free cloth and surface cleaning solution e.g. MEK
2. Apply replicating material into rod by slightly overfilling the slot

3. Use scraper to remove excess material from rod



4. Insert rod into fixture, then insert fixture into cylinder

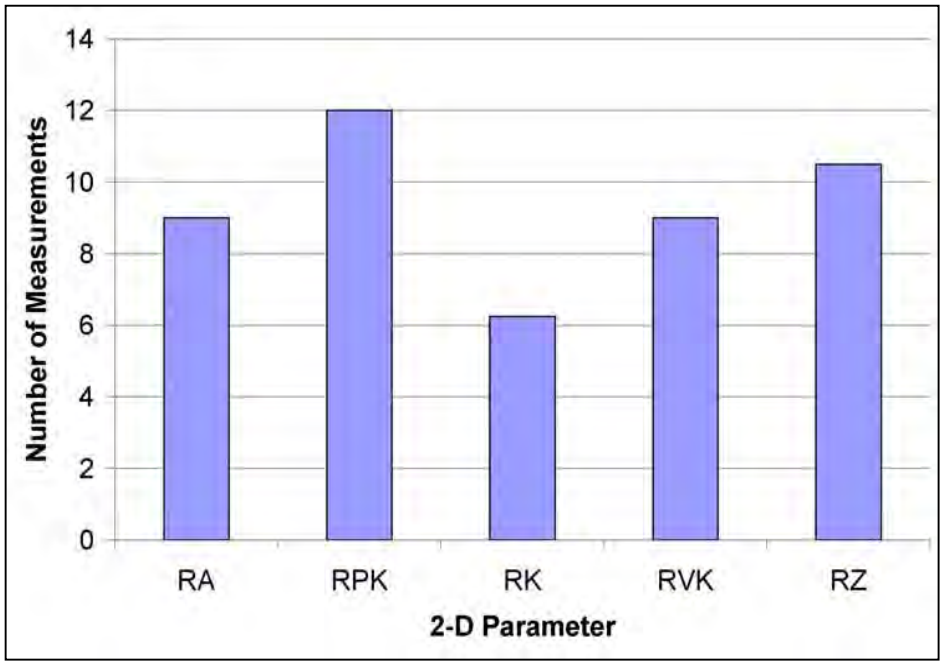
5. Energize air cylinder with 40 psi opening the valve (flip up) on top of the fixture
6. Let unit set with air pressure for 5 minutes
7. Turn off air valve, separate rod from liner and remove fixture from bore
8. Remove rod from fixture and place under interferometer

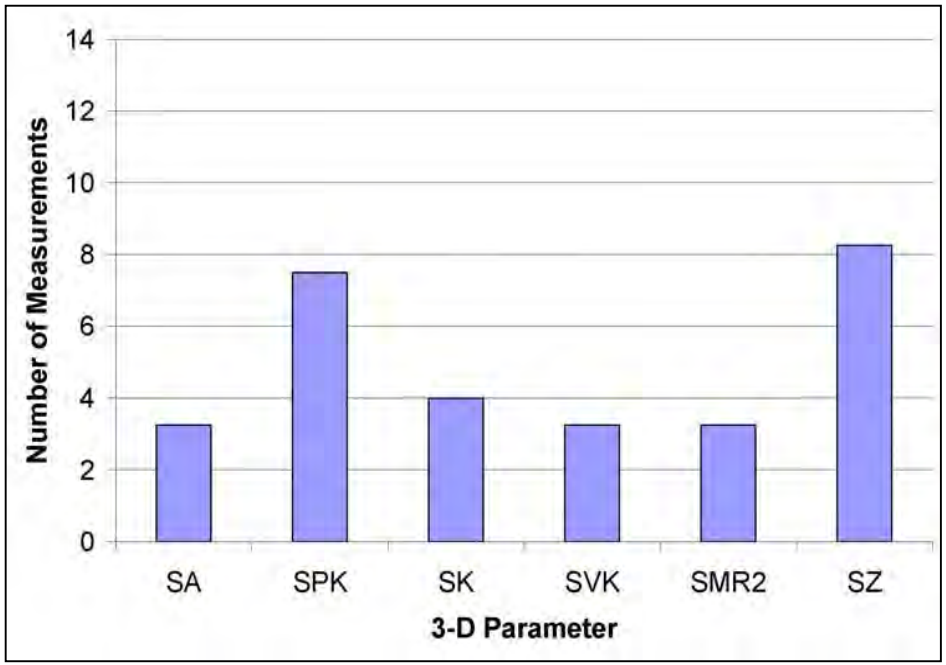


9. Make sure image on screen is flat as possible by using tilting knobs in front of holding stage
10. Scan and save image
11. Open SPIP software and bring up saved image
12. Invert image and run plan correction on image
13. Use roughness analysis tool to generate surface parameters in 3-D or 2-D data (using line profile)

Why Consider 3-D Parameters . . .

- **Improve finish measurement precision - an original objective**
- **Actual result - fewer readings required**





3-D Finish Parameter Advantages

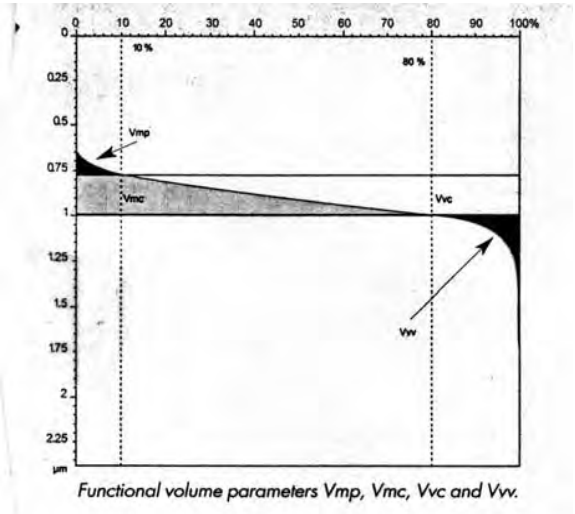
- **Fewer readings required**
- **Examines surface area - not a line**
- **Improves surface finish definition**
- **Significantly less number of measurements needed to keep parameter value within +/-10% of 95% confidence interval**

3-D Functional Parameters

New ISO 25178 Standard	Functional Parameter	Unit	Current DIN Standard
S_{MR}	Surface bearing area ratio or areal material ratio	%	
S_{MC}	Height of surface bearing area ratio or inverse areal material ratio	µm	S_{bi}
S_{XP}	Peak extreme height	µm	S_{MAX}
V_V	Void volume of the scale limited surface at a given height	$\mu m^3/\mu m$	
V_{MC}	Core material volume of the scale limited surface	$\mu m^3/\mu m^2$	
V_{VC}	Core void volume of the scale limited surface	$\mu m^3/\mu m^2$	S_{ci}
V_{VV}	Valley void volume of the scale limited surface		S_{vi}

- **Functional finish values are required in the development of effective models and an understanding of finish on oil consumption and wear**
- **Functional parameters are calculated from the Abbott-Firestone curve obtained by the integration of the height distribution on the whole surface**

Abbott-Firestone Curve



Functional volume parameters Vmp, Vmc, Vvc and Vvv.

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3-D Bore Surface Finish Data Provides . . .

- **Surface porosity**
  - **Percent area of surface porosity at location beneath mean core finish**
  - **Distribution of porosity size**
- **Particles in surface**
  - **Percent area occupied by aluminum particles (in hypereutectic aluminum surfaces) or silicon carbide or other hard particles (in Nikasil®-type coatings)**
  - **Particle size distribution - height of particle surface above mean of kernel roughness**
- **Wear**
  - **At top ring turn-around through 10μ - 100 μ (depending on objective)**
  - **At specific location between top and bottom turn-around**

Wear μm = (S_K + S_{PK}) before test - (S_K + S_{PK}) after test

Available 3-D Finish Measurement Information (Alternate Cylinder Bore Surfaces)

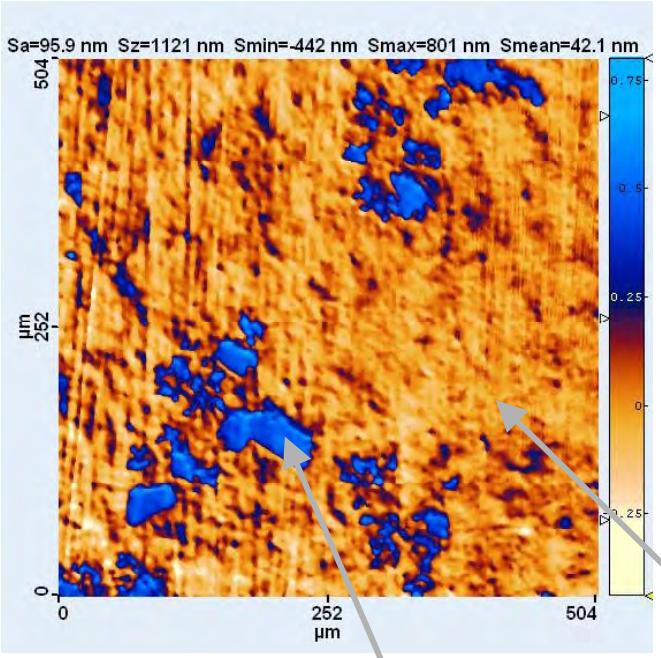
- **2-D surface image (similar to faxfilm) - torn/folded material, crosshatch angle**
- **3-D surface image**
- **2-D/3-D height parameters - S_A/R_A, S_Z/R_Z, S_P/R_{PK}, S_V/R_{VK}, S_K/R_K finish and hard particle height vs. core material**
- **Functional wear parameters - S_{MR} bearing surface area, S_{MC} height of surface bearing area**
- **Functional lubrication/oil consumption parameters - V_V void volume of scale limited surface at height, V_{VC} core void volume of surface**
- **Additional data - oil consumption, surface porosity, % area occupied by and size distribution of hard particles**

Typical Hypereutectic Aluminum Cylinder Bore Finish Data

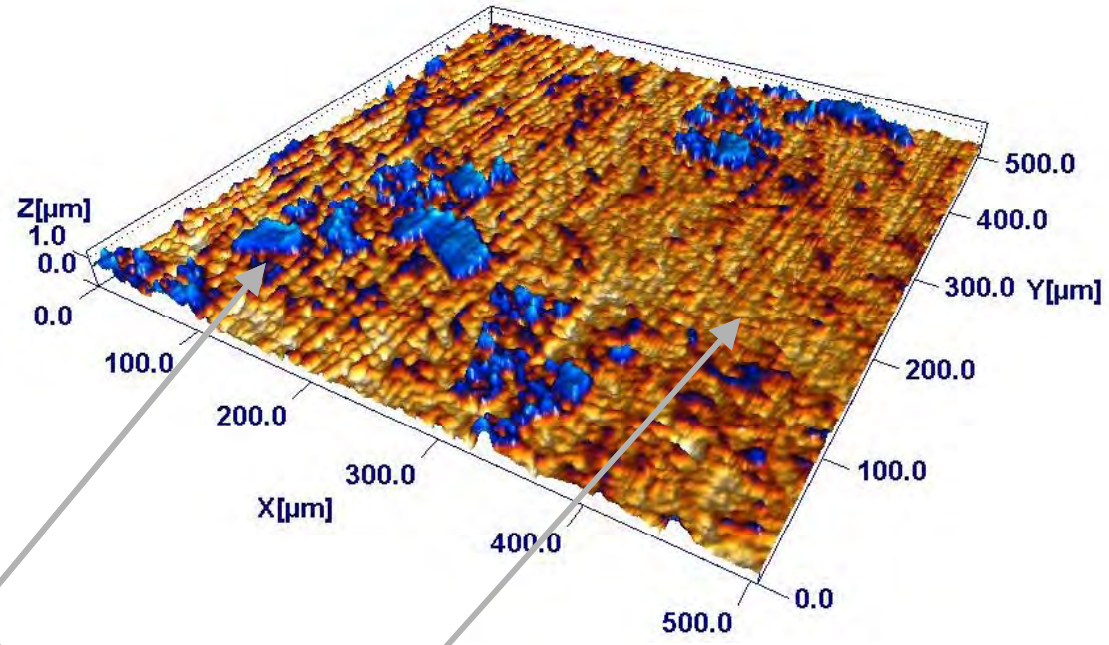
From Top (mm)	3-D Parameters from Replicate Scan (µm)											
	S_A	S_Z	S_{PK}	S_K	S_{VK}	S_{MIN}	S_{MAX}	S_1 ht	% Si	% Pores	S_{bi}	S_{ci}
45	0.082	1.056	0.212	0.222	0.098	-0.508	0.628	1.136	29.7	0.83	0.479	1.820
60	0.083	1.208	0.253	0.215	0.072	-0.436	0.952	1.388	18.4	0.85	0.509	1.760
75	0.103	1.110	0.315	0.269	0.080	-0.367	0.820	1.187	30.8	2.72	0.419	2.040
90	0.113	1.646	0.322	0.307	0.117	-0.909	1.095	2.004	23.8	0.11	0.484	1.820
Avg	0.095	1.255	0.276	0.253	0.092	-0.555	0.874	1.429	25.67	1.128	0.473	1.86
Min	0.082	1.056	0.212	0.215	0.072	-0.909	0.628	1.136	18.4	0.11	0.419	1.760
Max	0.113	1.646	0.322	0.307	0.117	-0.367	1.095	2.004	30.8	2.72	0.509	2.040

Typical Hypereutectic Cylinder Bore Surface

2-D Image



3-D Image



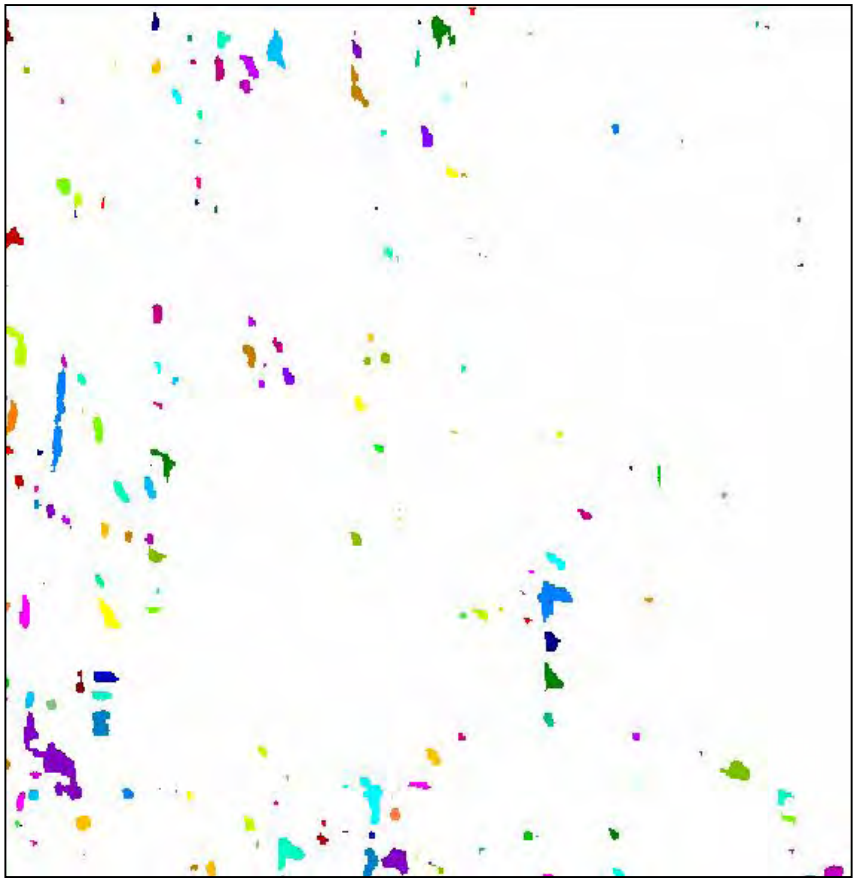
Silicon particle

Aluminum matrix

Percent Silicon Particle and Casting Porosity Distribution

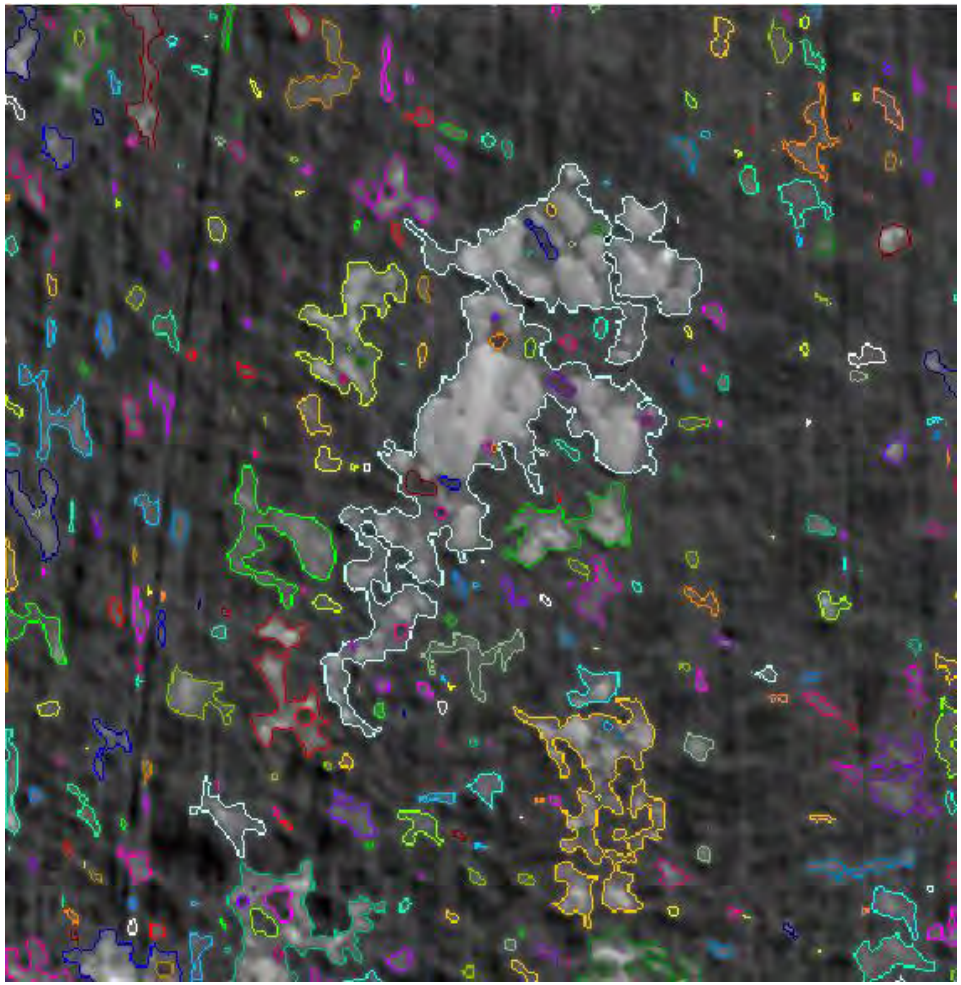
Particle Area at Surface

Porosity Area at Surface



Percent Silicon Particle Distribution

Particle Area at Surface



Percentage Area of Coverage

Grain Analysis Result

ID: 0 Exclude Remember

	Selected	Mean	SD
Area:	1.1E+6	1.7E+8	9.7E+8
Volume:	14494	2.1E+10	1.9E+11
Z Mean:	100.0	132.0	35.53
Z Range	100.0	185.2	119.5
Length:	1488	1.526E+	2.36E+4
Mean Width:	744.0	4317	4800
Diameter:	1187	9004	11732
Perimeter:	4209	59341	1.6E+5

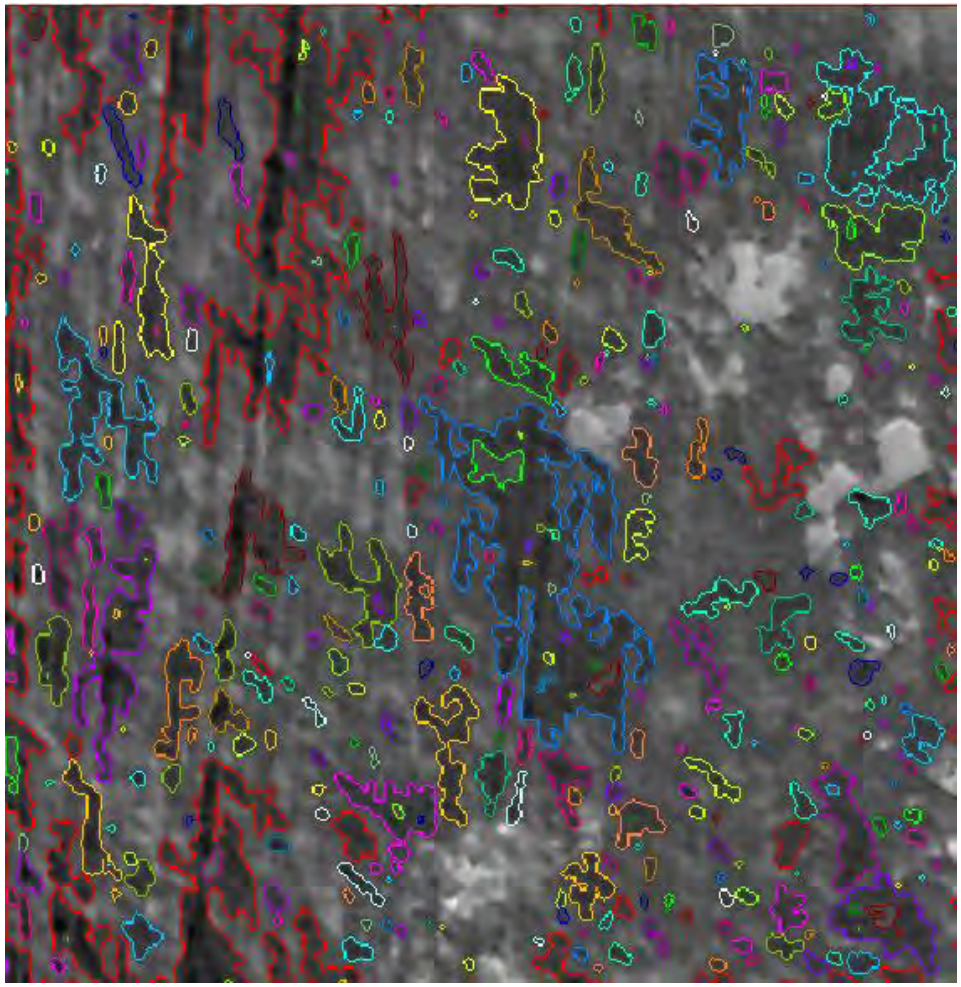
Detected: 327 Coverage % 21.6

Include elements on border ☑ Close Help

Silicon above 10% plane

Percent Casting Porosity Distribution

Porosity Area below Surface



Percentage Area of Coverage

Grain Analysis Result

ID: 0 Exclude Remember

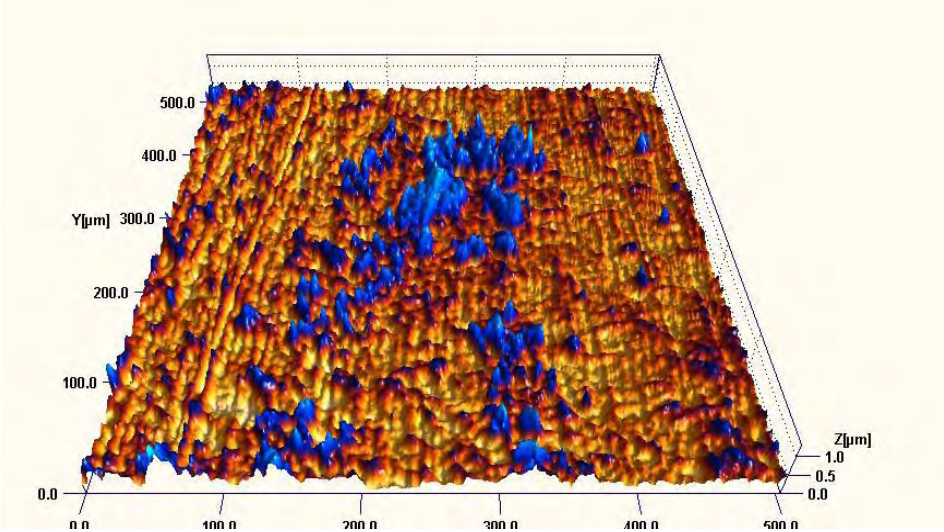
	Selected	Mean	SD
Area:	8.7E+7	1.5E+8	5.6E+8
Volume:	7.4E+9	7E+9	3.3E+10
Z Mean:	-125.0	-63.20	20.70
Z Range	235.1	95.48	59.05
Length:	4.116E+	1.561E+	2.324E+
Mean Width:	2125	4006	4148
Diameter:	10553	8711	10677
Perimeter:	90489	59694	1.4E+5

Detected: 431 Coverage %: 24.5

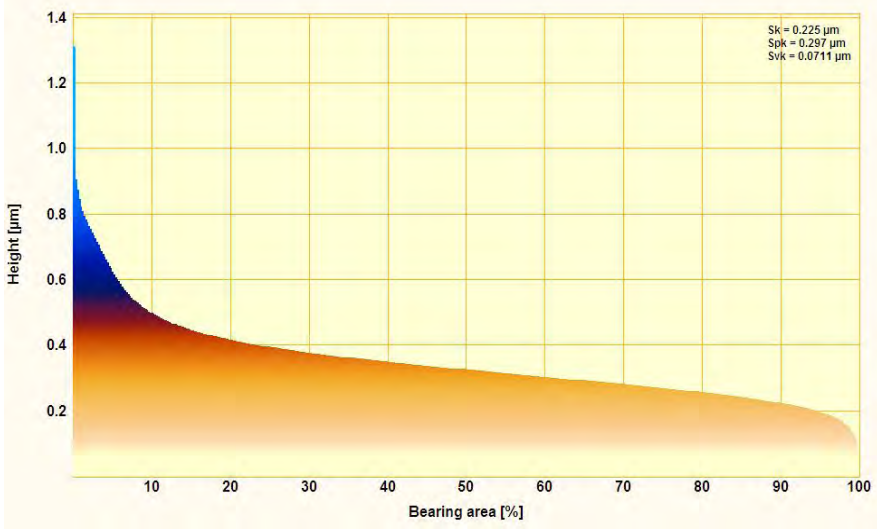
Include elements on border ☑ Close Help

Porosity below 10% plane

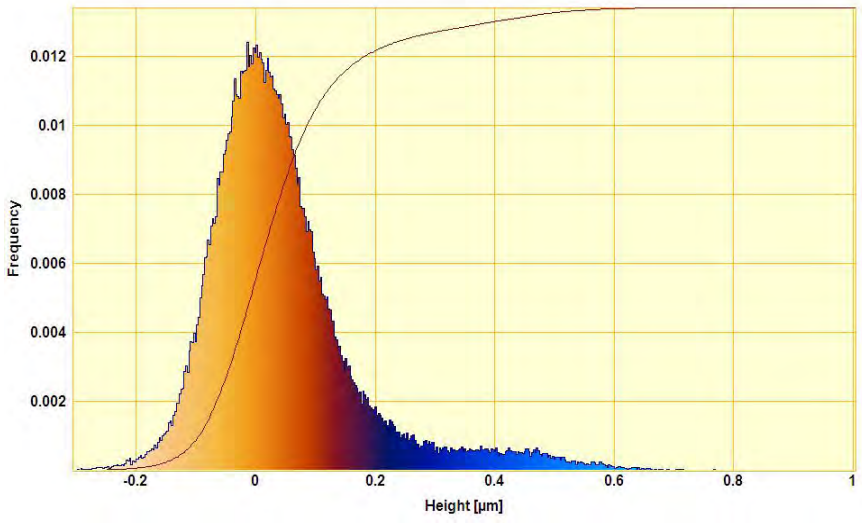
Graphical Representation of Finish



3-D Surface



Bearing Area



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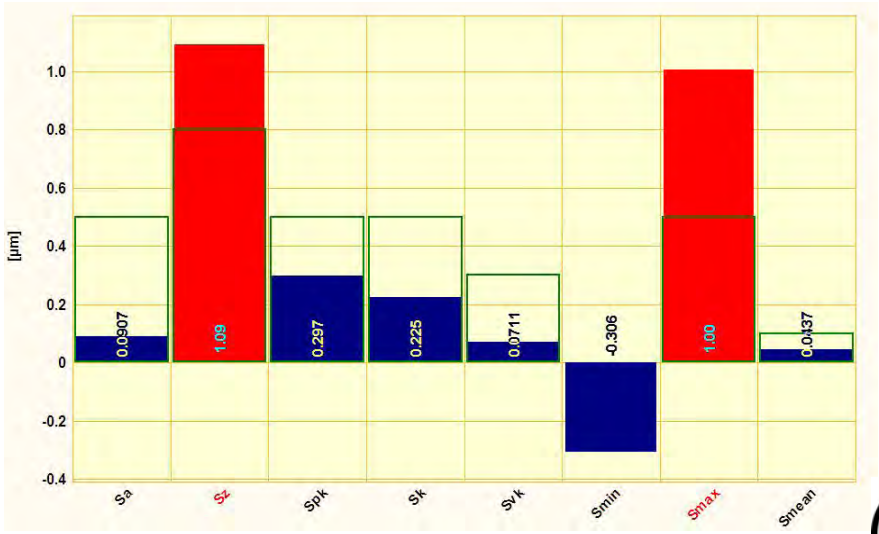
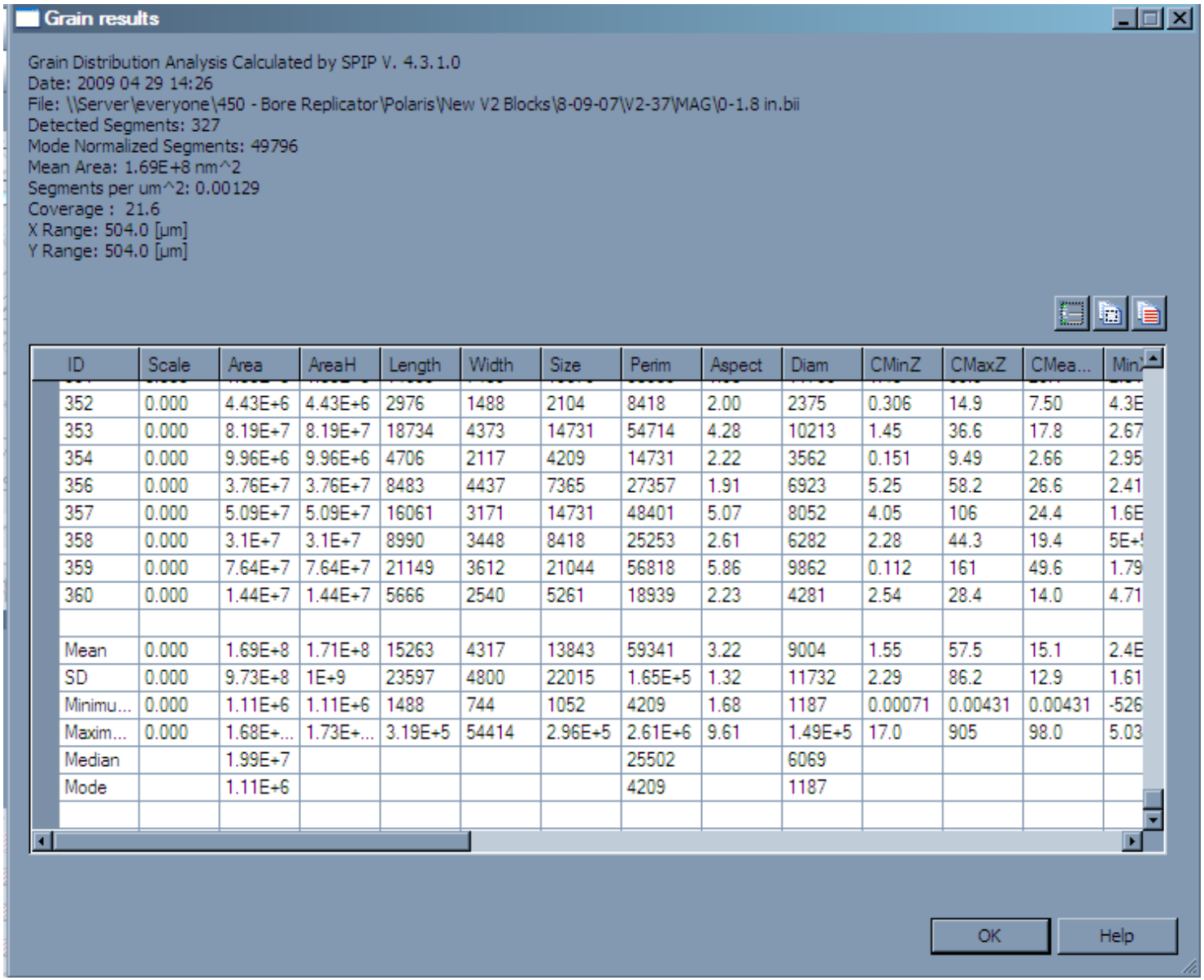
Histogram



Roughness

Silicon (Hard) Particle Analysis Data



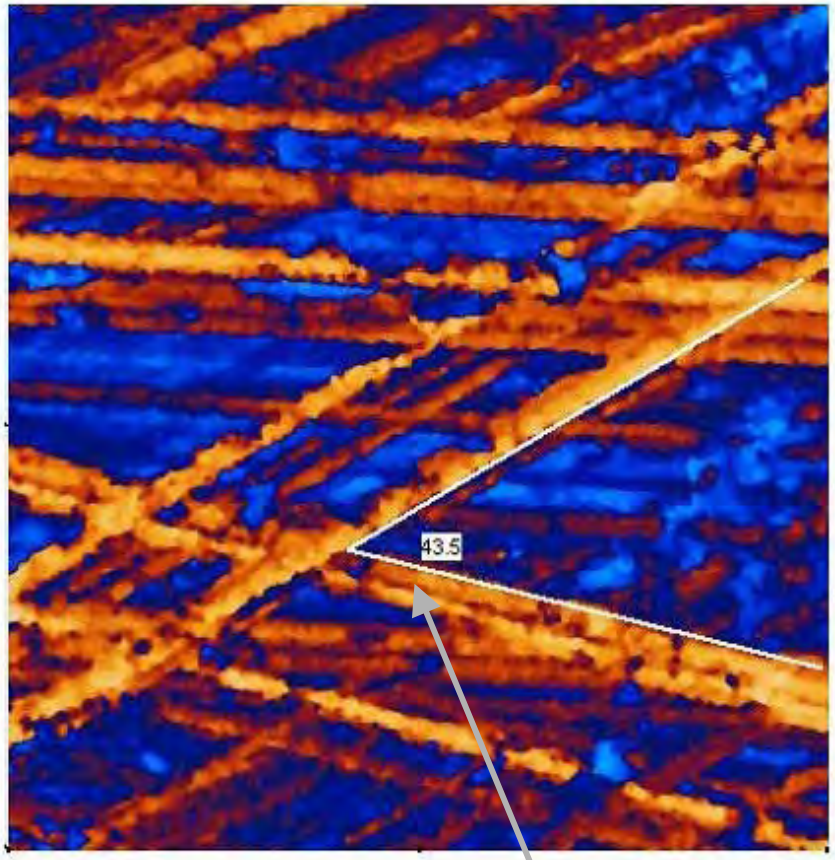
Grain results

Grain Distribution Analysis Calculated by SPIP V. 4.3.1.0
Date: 2009 04 29 14:26
File: \\Server\everyone\450 - Bore Replicator\Polaris\New V2 Blocks\8-09-07\V2-37\MAG\0-1.8 in.bii
Detected Segments: 327
Mode Normalized Segments: 49796
Mean Area: 1.69E+8 nm^2
Segments per um^2: 0.00129
Coverage : 21.6
X Range: 504.0 [µm]
Y Range: 504.0 [µm]

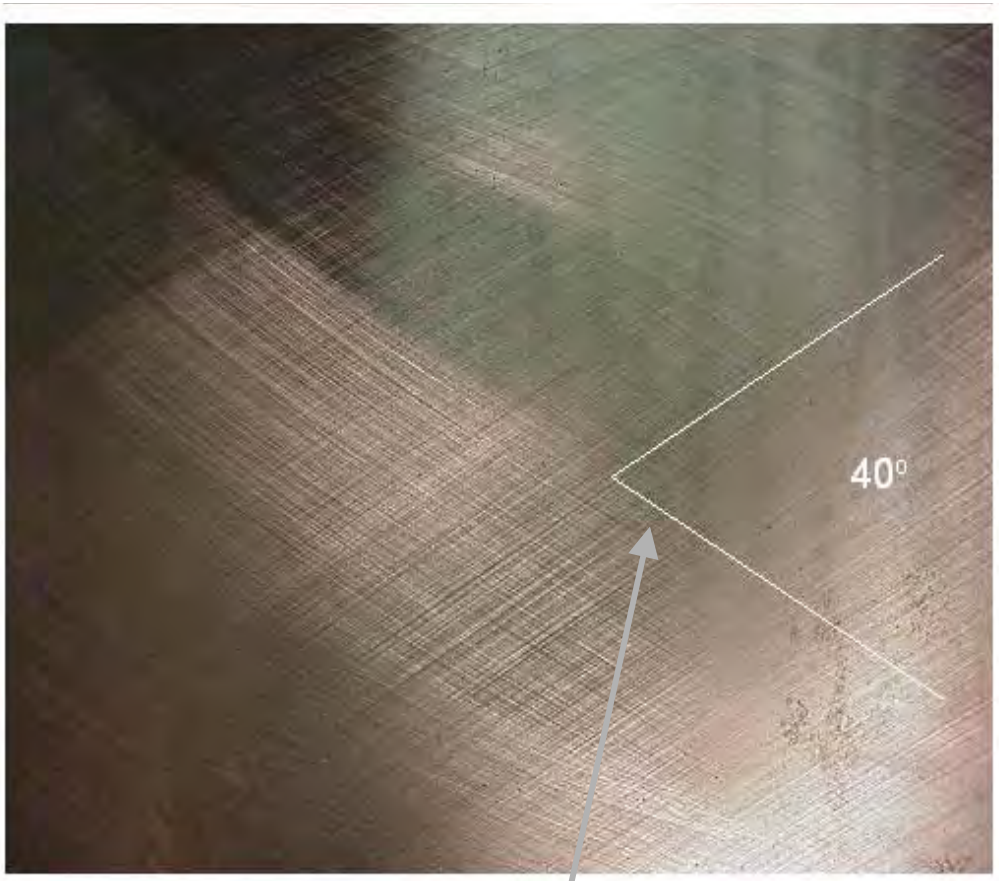
ID	Scale	Area	AreaH	Length	Width	Size	Perim	Aspect	Diam	CMinZ	CMaxZ	CMea...	Min
352	0.000	4.43E+6	4.43E+6	2976	1488	2104	8418	2.00	2375	0.306	14.9	7.50	4.3E
353	0.000	8.19E+7	8.19E+7	18734	4373	14731	54714	4.28	10213	1.45	36.6	17.8	2.67
354	0.000	9.96E+6	9.96E+6	4706	2117	4209	14731	2.22	3562	0.151	9.49	2.66	2.95
356	0.000	3.76E+7	3.76E+7	8483	4437	7365	27357	1.91	6923	5.25	58.2	26.6	2.41
357	0.000	5.09E+7	5.09E+7	16061	3171	14731	48401	5.07	8052	4.05	106	24.4	1.6E
358	0.000	3.1E+7	3.1E+7	8990	3448	8418	25253	2.61	6282	2.28	44.3	19.4	5E+
359	0.000	7.64E+7	7.64E+7	21149	3612	21044	56818	5.86	9862	0.112	161	49.6	1.79
360	0.000	1.44E+7	1.44E+7	5666	2540	5261	18939	2.23	4281	2.54	28.4	14.0	4.71
Mean	0.000	1.69E+8	1.71E+8	15263	4317	13843	59341	3.22	9004	1.55	57.5	15.1	2.4E
SD	0.000	9.73E+8	1E+9	23597	4800	22015	1.65E+5	1.32	11732	2.29	86.2	12.9	1.61
Minimu...	0.000	1.11E+6	1.11E+6	1488	744	1052	4209	1.68	1187	0.00071	0.00431	0.00431	-526
Maxim...	0.000	1.68E+...	1.73E+...	3.19E+5	54414	2.96E+5	2.61E+6	9.61	1.49E+5	17.0	905	98.0	5.03
Median		1.99E+7					25502		6069				
Mode		1.11E+6					4209		1187				

OK Help

Cross-hatch Angle Determination

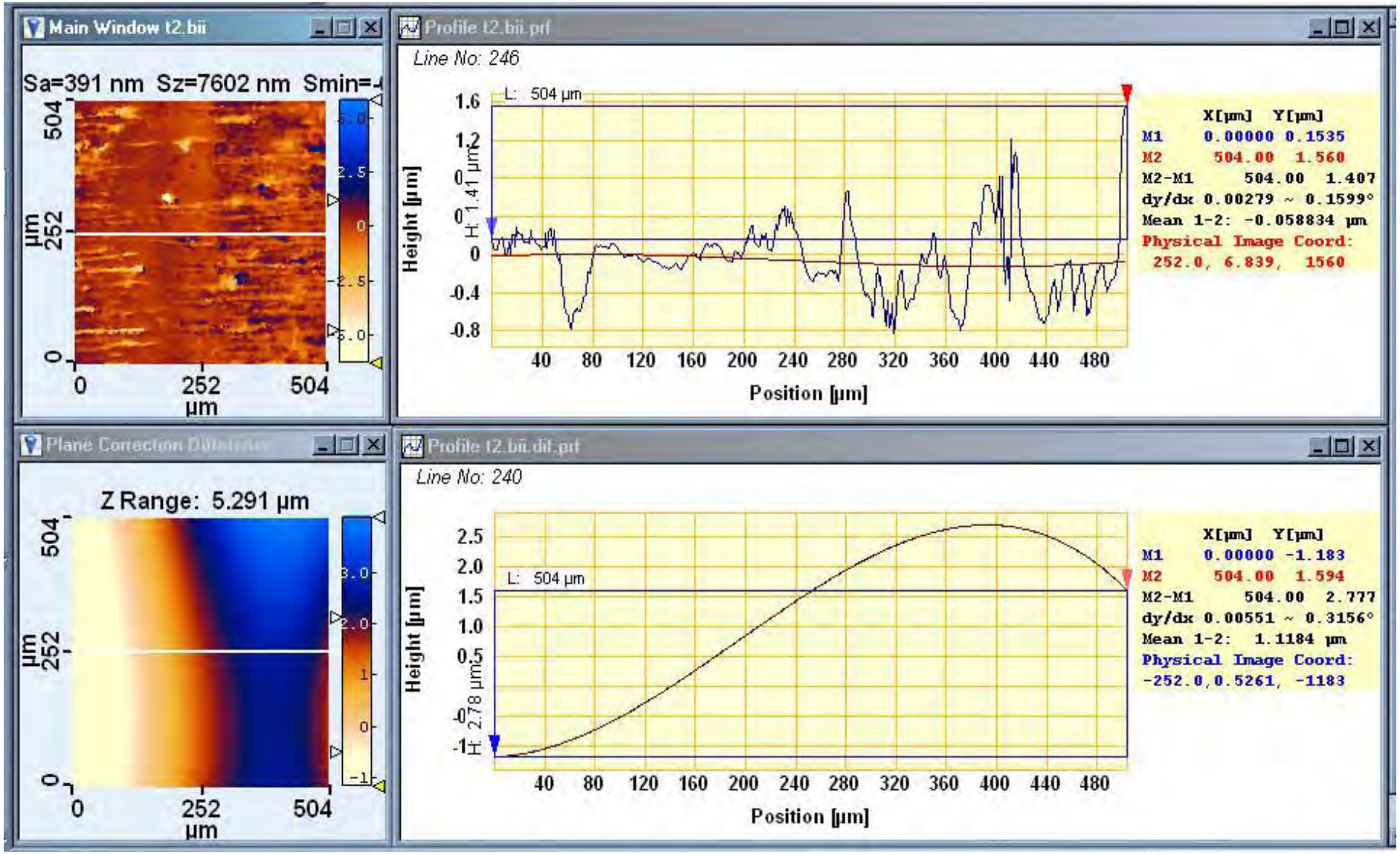


Crosshatch Angle From SEE 3-D



Crosshatch Angle from Liner Section

Line and Form Profiles for 2-D Parameters



Accuracy of Various Surface Finish Measuring Equipment