

SEE 3-D

# Surface Evaluation Equipment

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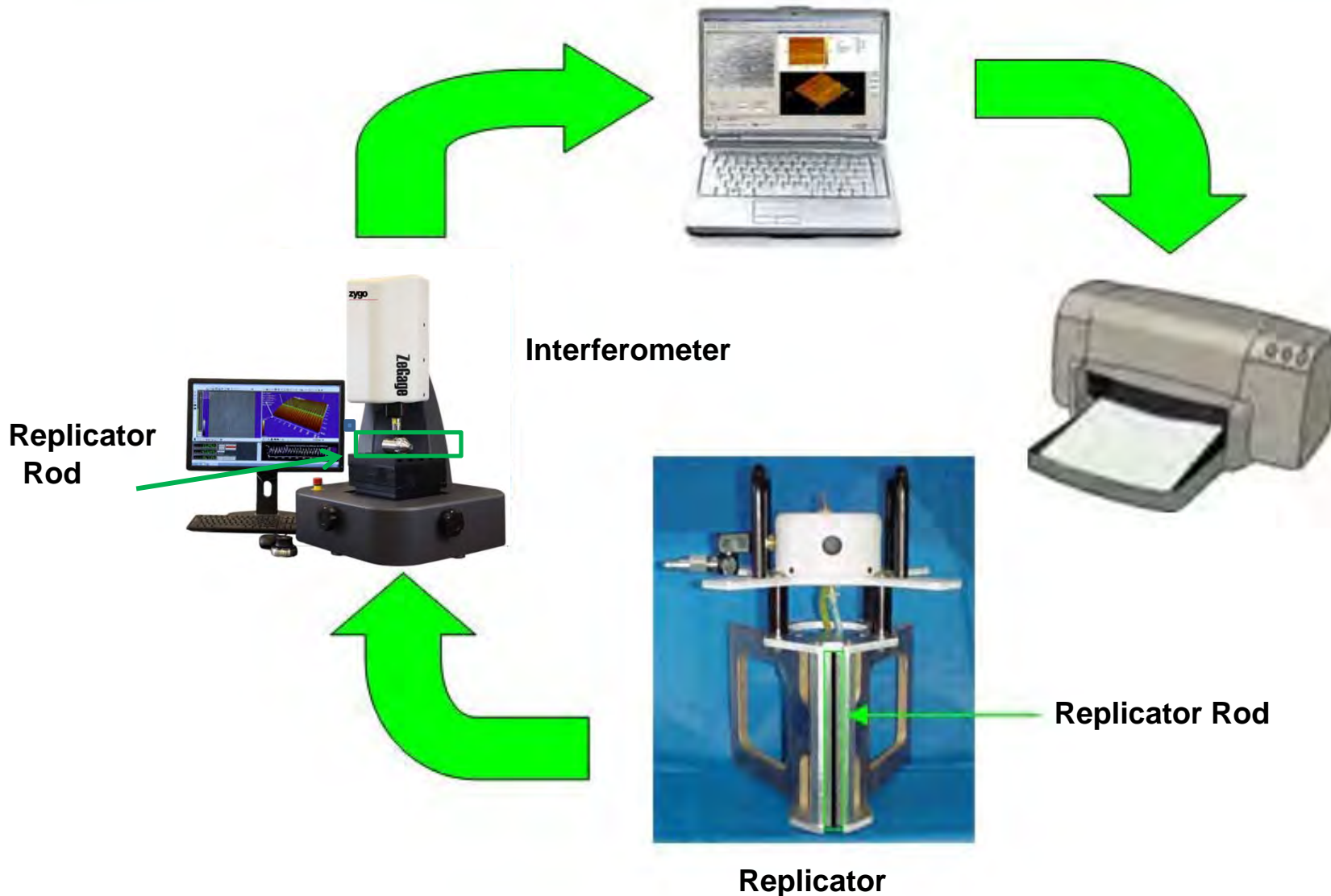
C-K Engineering, Inc.

# SEE 3-D System Overview

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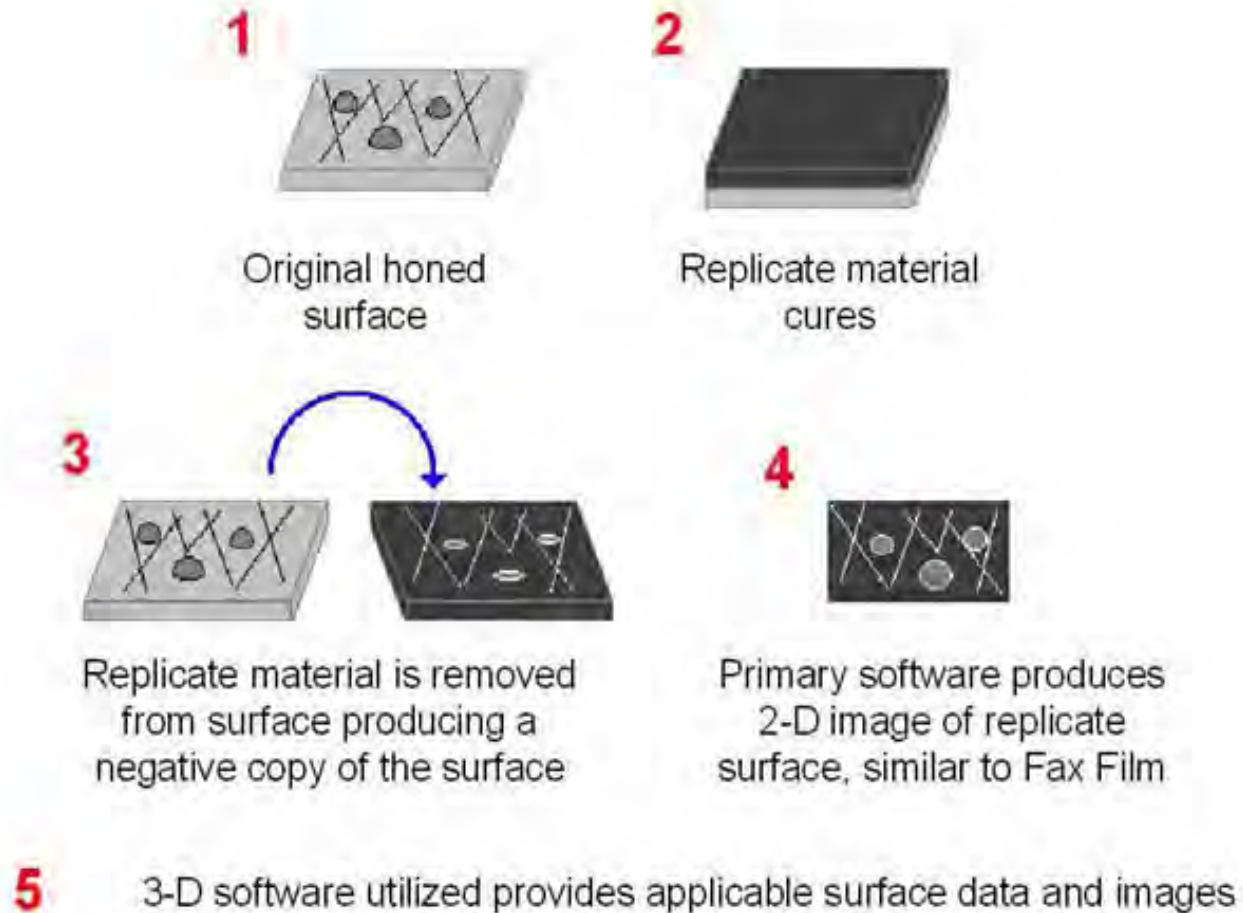
- Creates a permanent replicate of the cylinder bore surface
- Uses interferometer to take 3-D image and acquire data from replicate
- Automatically generates a detailed surface finish report including quantification of:
  - 3-D Finish
  - 2-D Finish
  - Cross Hatch Angle
  - Torn and Folded Material

# SEE 3-D System Components



# Replication Process

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# Steps to Make Replicates and Acquire Data



1. Clean specimen surface with lint free cloth and surface cleaning solution
2. Insert rod into fixture and apply replicating material into rod by slightly overfilling the slot

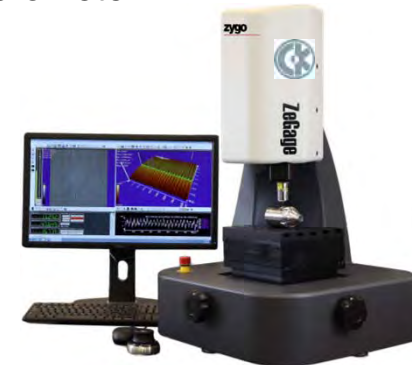


3. Use scraper to remove excess material from rod



4. Insert fixture into cylinder

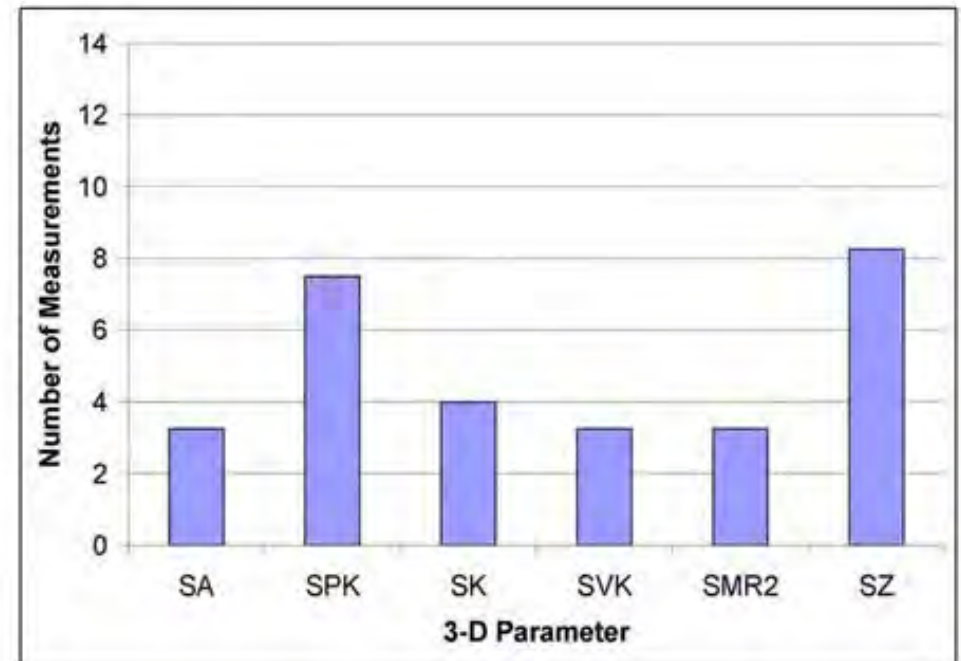
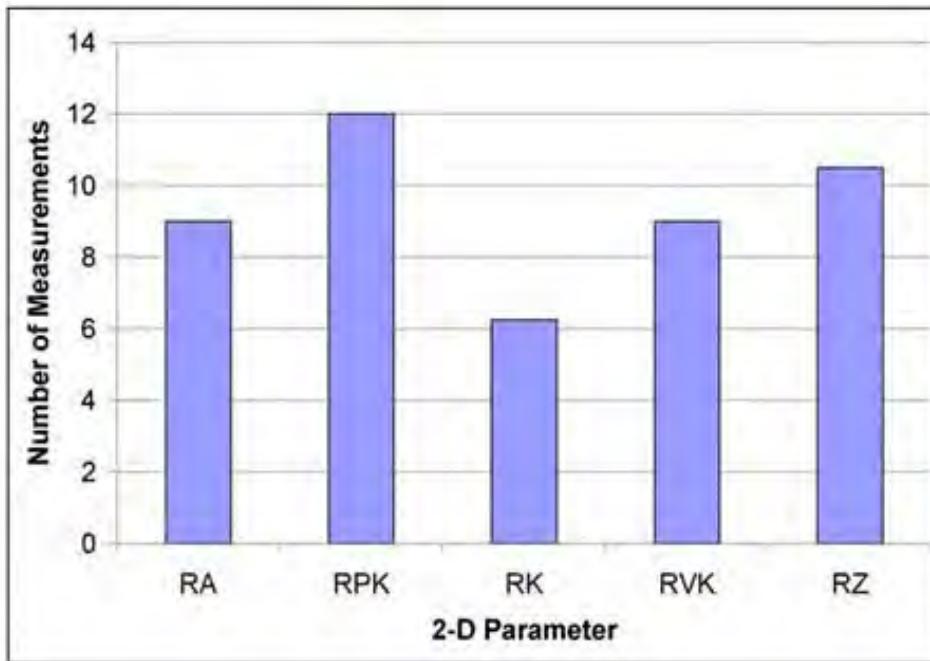
5. Energize air cylinder with 60 psi opening the valve (flip up) on top of the fixture
6. Let unit set with air pressure for 8 minutes
7. Turn off air valve, separate rod from liner and remove fixture from bore
8. Remove rod from fixture and place under interferometer



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
- Fewer measurements required
- Actual result – Multiple readings are automatically generated during analysis of replicate



# 3-D Finish Parameter Advantages

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- 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
- Excludes effect of porosity in porous surfaces  
I.E. plasma coatings





# 3-D Functional Parameters

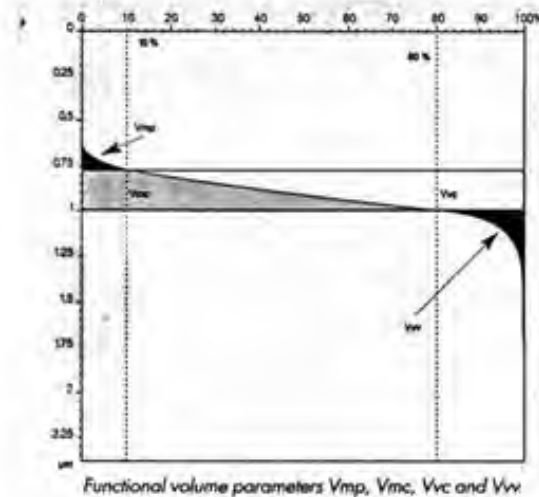
ISO Standard

Additional CKE Parameters

CKE Proposed 3-D parameters	Optimal Parameter Range	SAE 2001-3550 Stevens Hill 2-D Parameters
$S_{10z}$ : Mean Peak to Valley Height	(Optimal range: 8-24 $\mu\text{m}$ )	$R_z$ ISO 2.5-4.0 $\mu\text{m}$
$S_{vk}$ : Reduced Valley Depth.	(Optimal range: 0.5-1.2 $\mu\text{m}$ )	$R_{vk}$ 0.7-1.0 $\mu\text{m}$
$S_k$ : Core Roughness Depth	(Optimal range: 0.4-0.8 $\mu\text{m}$ )	$R_k$ 0.6-1.0 $\mu\text{m}$
$S_{pk}$ : Reduced Peak Height	(Optimal range: 0.4-1.5 $\mu\text{m}$ )	$R_{pk}$ 0.1-0.4 $\mu\text{m}$
$S_{bj}$ : Surface Bearing Index	(Optimal range: 0.8-1.5)	
$S_{ci}$ : Core Fluid Retention Index.	(Optimal range: 0.3-1.0)	
TFM: Torn and Folded Material	(Optimal range $\geq 6$ ) (1-10 scale)	12 max (1-15 scale)
X-Hatch: Hone Cross-Hatch Angle	(Optimal range: 25-35 Degrees)	25-35 degrees
Porosity: Total Porosity Area as a Percentage of Scan Area (Sume)	(Optimal range: 0.0-1.5 %)	

- 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





# 3-D Bore Surface Finish Data Provides . . .

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- **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 10 $\mu$  - 100  $\mu$  (depending on objective)
- At specific location between top and bottom turn-around  
Wear  $\mu\text{m} = (S_K + S_{PK})$  before test -  $(S_K + S_{PK})$  after test



# Available 3-D Finish Measurement Information Cast Iron & (Alternate Cylinder Bore Surfaces)

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- 2-D surface image (similar to faxfilm) - torn/folded material, crosshatch angle (automatic quantitative evaluation)
- 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 in case of alternate cylinder bore materials



# Typical Hypereutectic Aluminum Cylinder Bore Finish Data

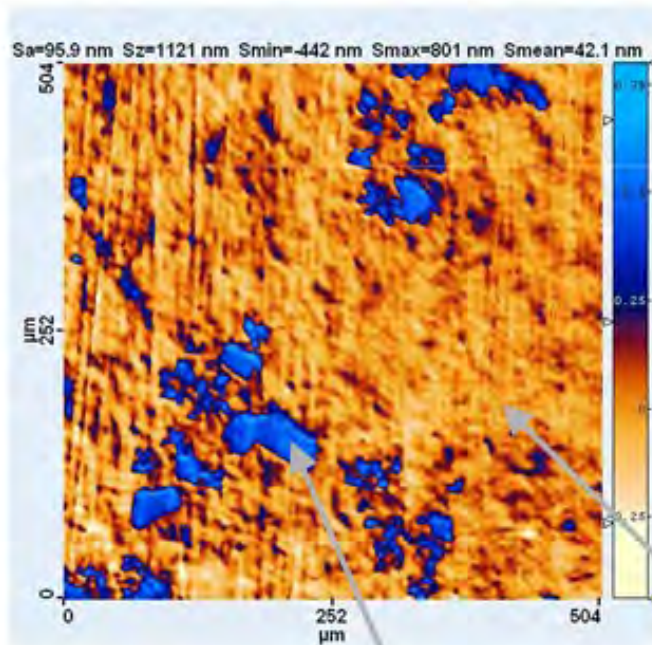
## 3-D Parameters from Replicate Scan ( $\mu\text{m}$ )

From Top (mm)	S <sub>A</sub>	S <sub>Z</sub>	S <sub>PK</sub>	S <sub>K</sub>	S <sub>VK</sub>	S <sub>MIN</sub>	S <sub>MAX</sub>	S <sub>1 ht</sub>	% Si	% Pores	S <sub>bi</sub>	S <sub>ci</sub>
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

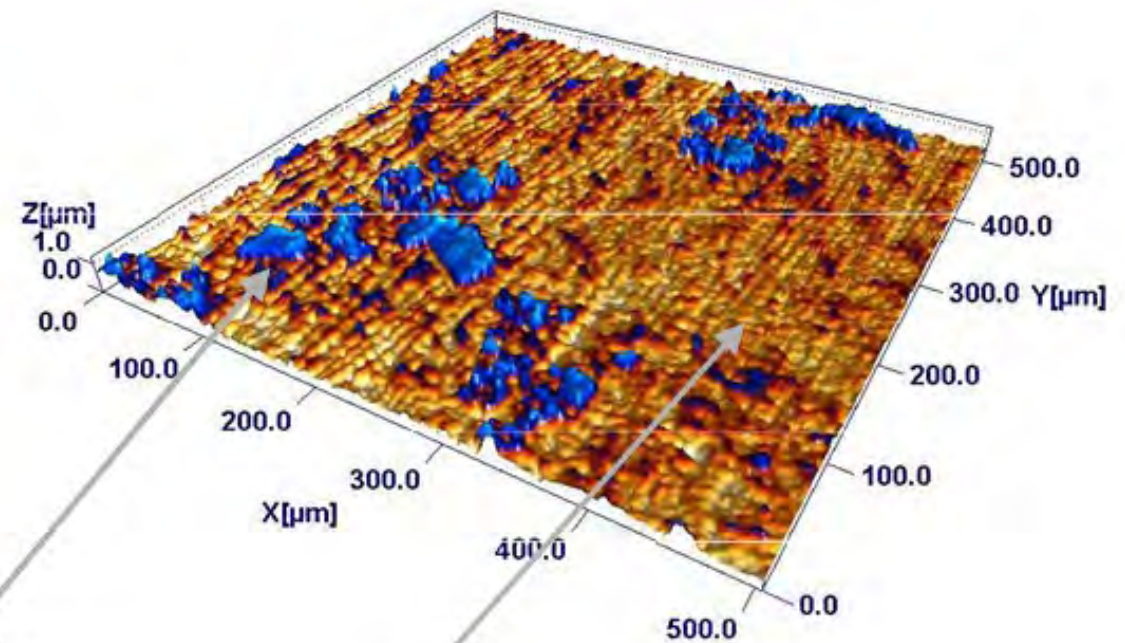


# Typical Hypereutectic Cylinder Bore Surface

2-D Image



3-D Image



Silicon particle

Aluminum matrix

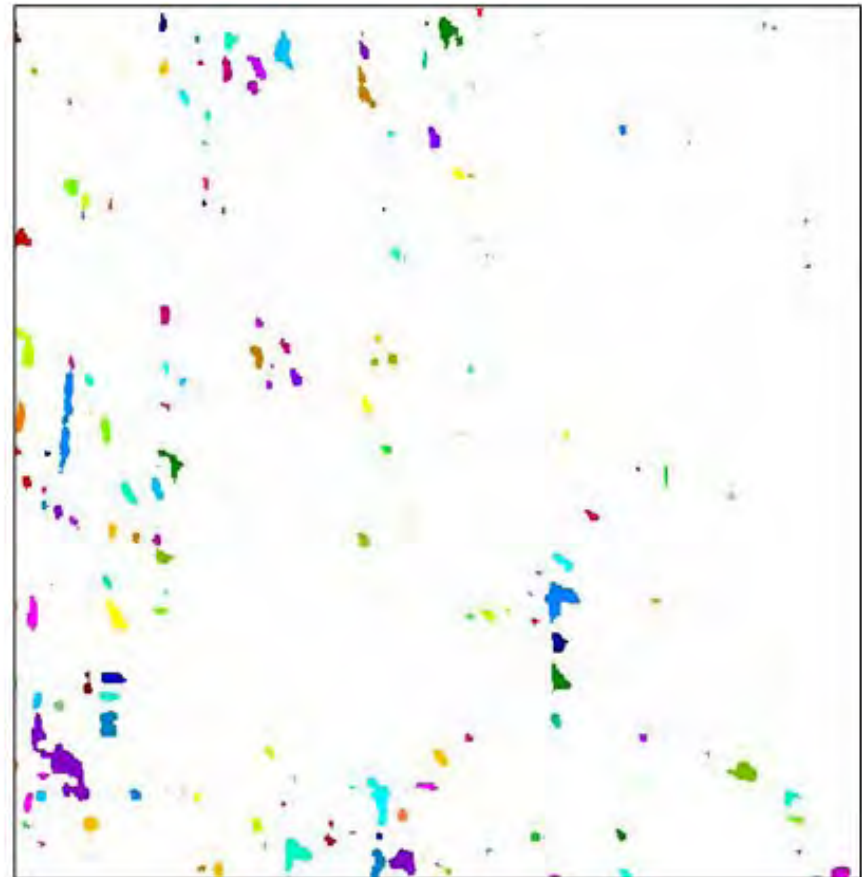
# Percent Silicon Particle and Casting Porosity Distribution – 390 Aluminum

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**Particle Area at Surface**



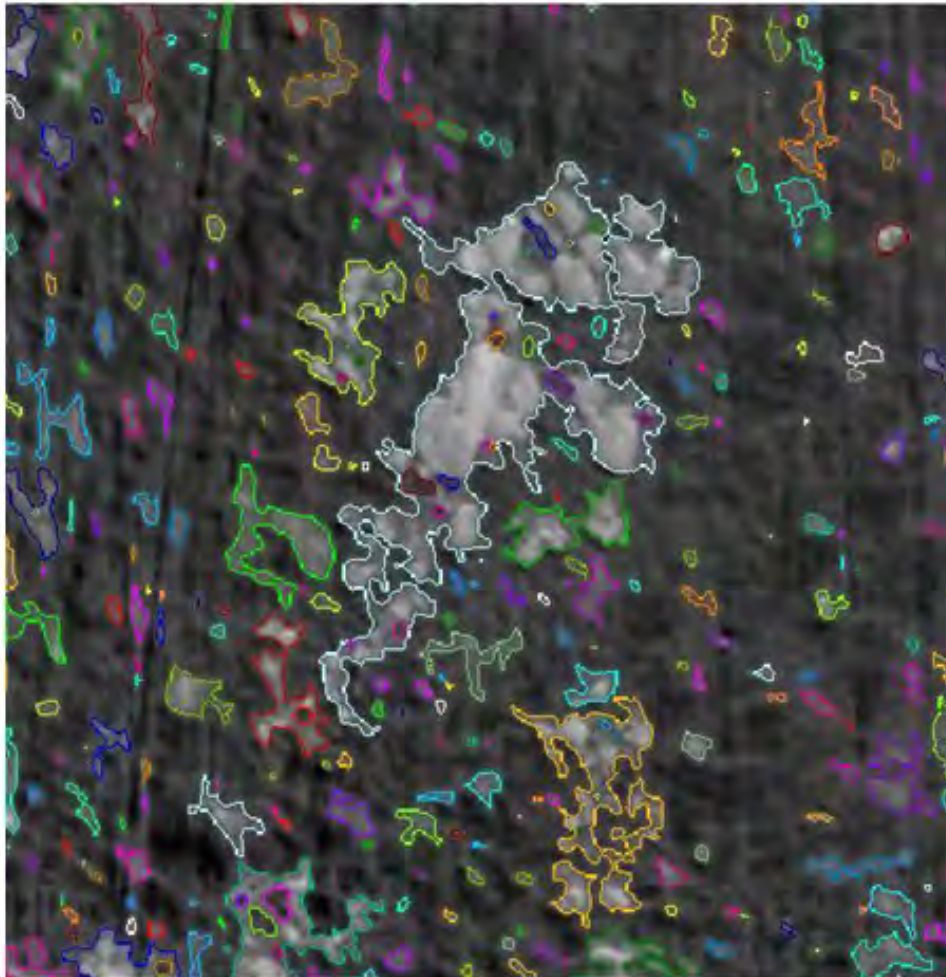
**Porosity Area at Surface**





# Percent Silicon Particle Distribution

Particle Area at Surface



Percentage Area of Coverage

Grain Analysis Result

ID:  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:  Coverage %

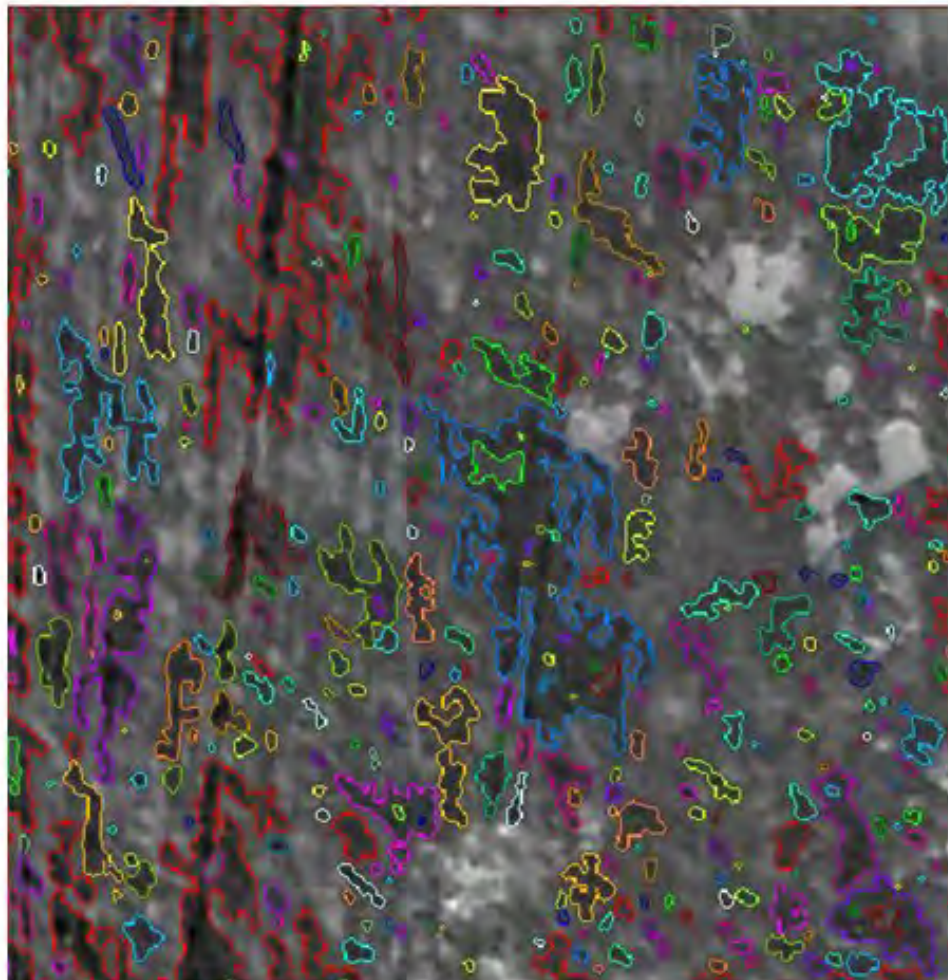
Include elements on border

Close Help

Silicon above 10% plane

# Percent Casting Porosity Distribution 390 Aluminum

Porosity Area below Surface



Percentage Area of Coverage

Grain Analysis Result

ID:  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:  Coverage %

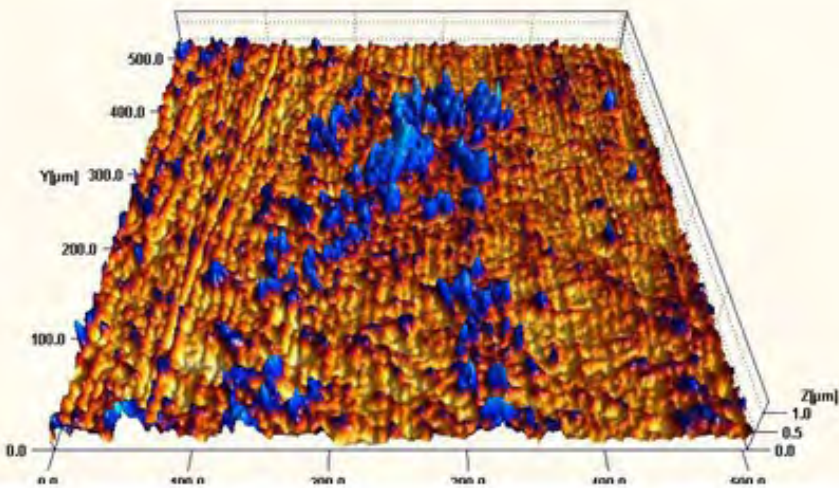
Include elements on border

Close Help

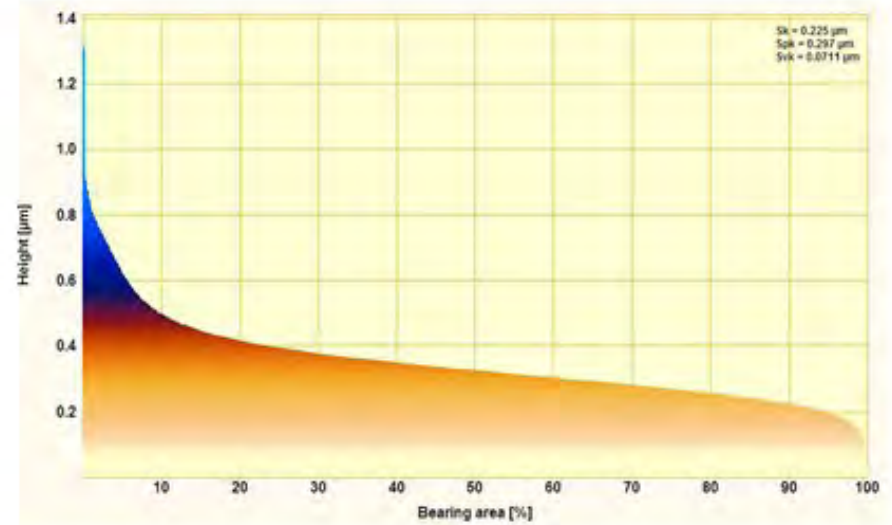
Porosity below 10% plane



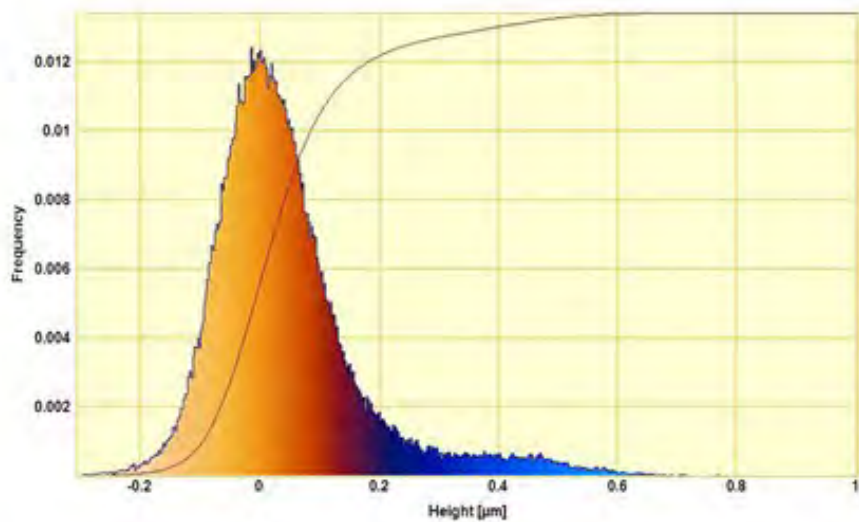
# Graphical Representation of Finish 390 Aluminum



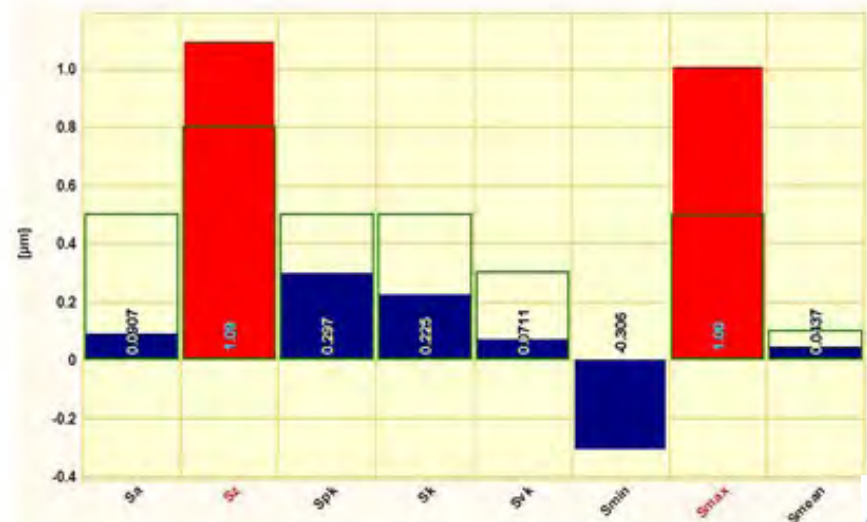
3-D Surface



Bearing Area



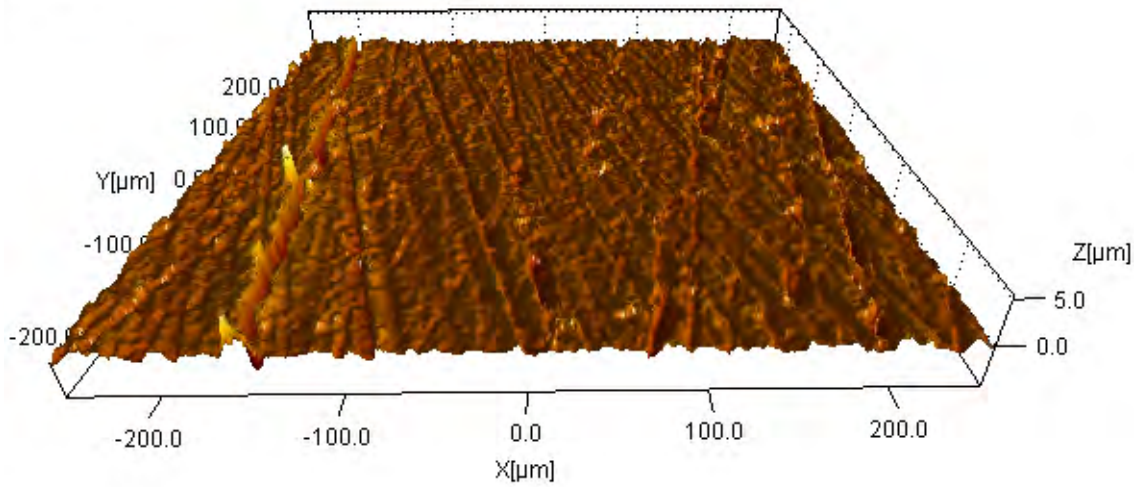
Histogram



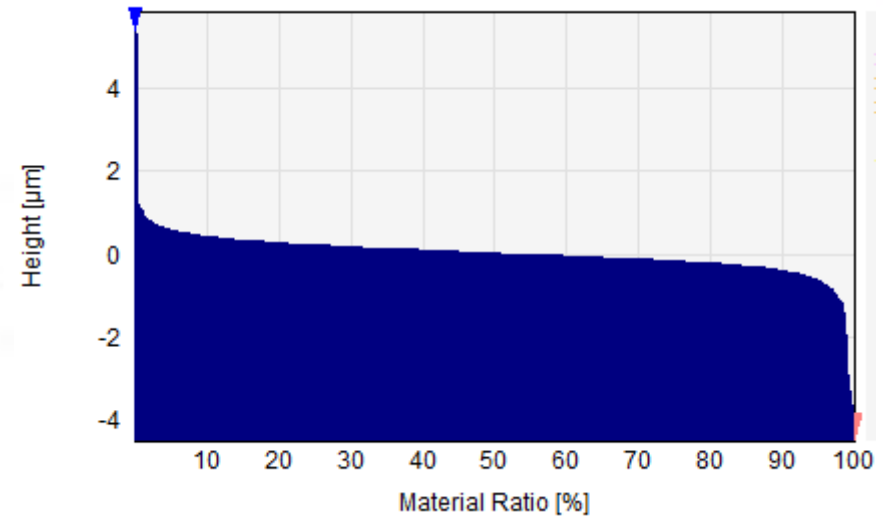
Roughness

# Graphical Representation of Finish Cast Iron

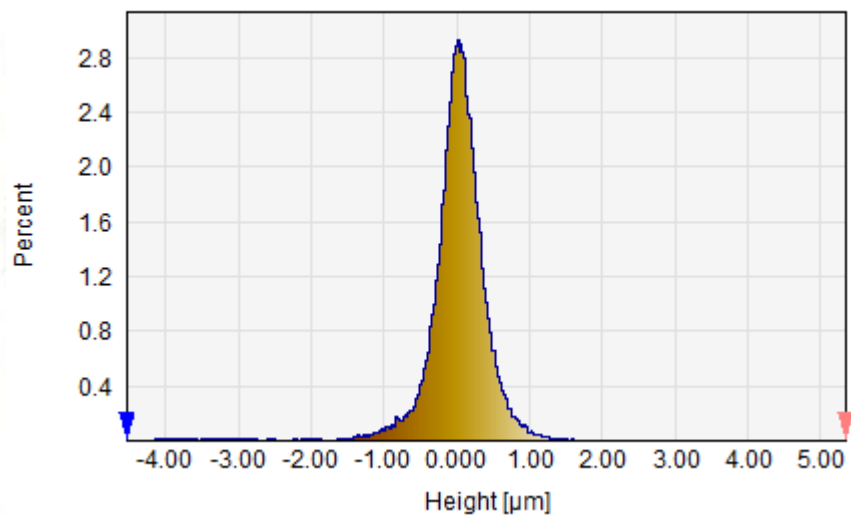
hd.5.0.1.top.1 3D View.asc



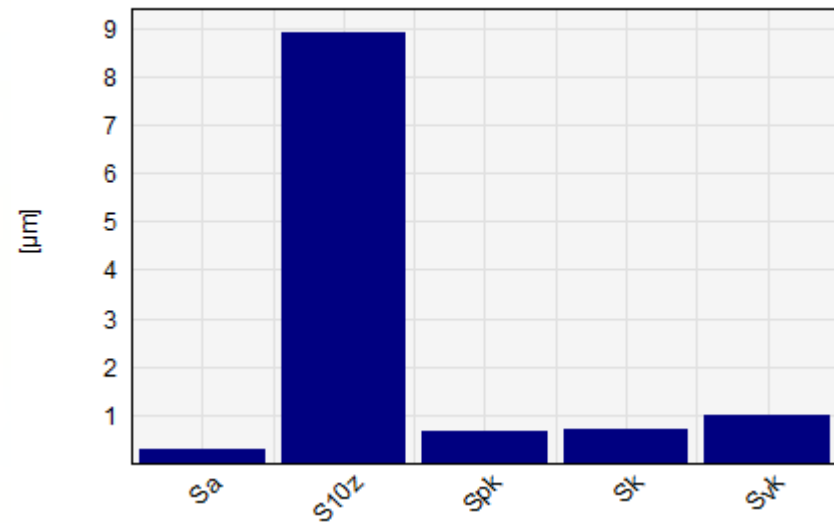
**3-D Surface**



**Bearing Area**



**Histogram**



**Roughness**



# Silicon (Hard) Particle Analysis Data

**Grain results**

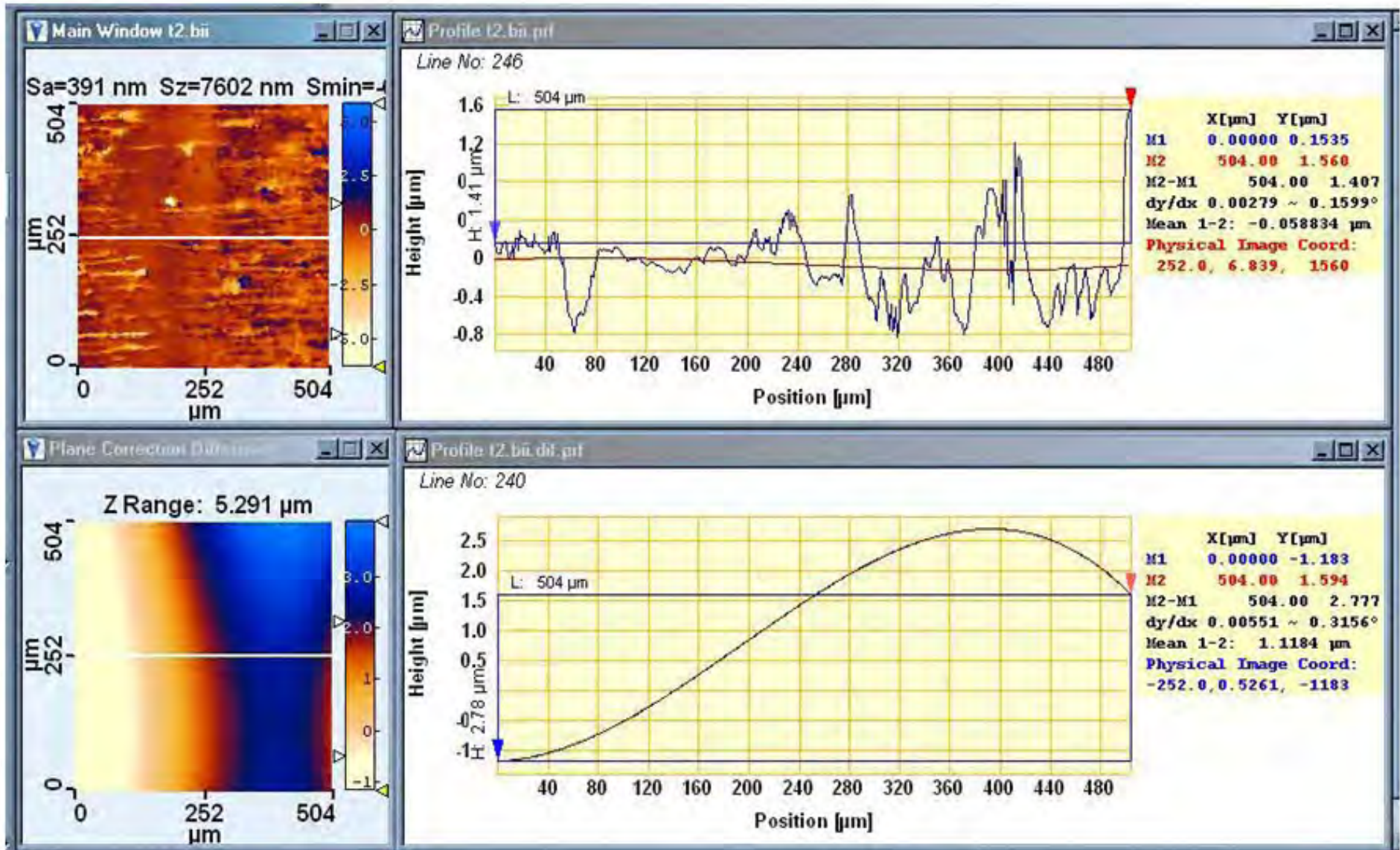
Grain Distribution Analysis Calculated by SPIP V. 4.3.1.0  
 Date: 2009 04 29 14:26  
 File: \\Server\everyone\450 - Bore Replicator\Polaris\New V2 Blocks\8-09-07\V2-37\MAG\0-1.8 in.bi  
 Detected Segments: 327  
 Mode Normalized Segments: 49796  
 Mean Area: 1.69E+8 nm<sup>2</sup>  
 Segments per um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

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				

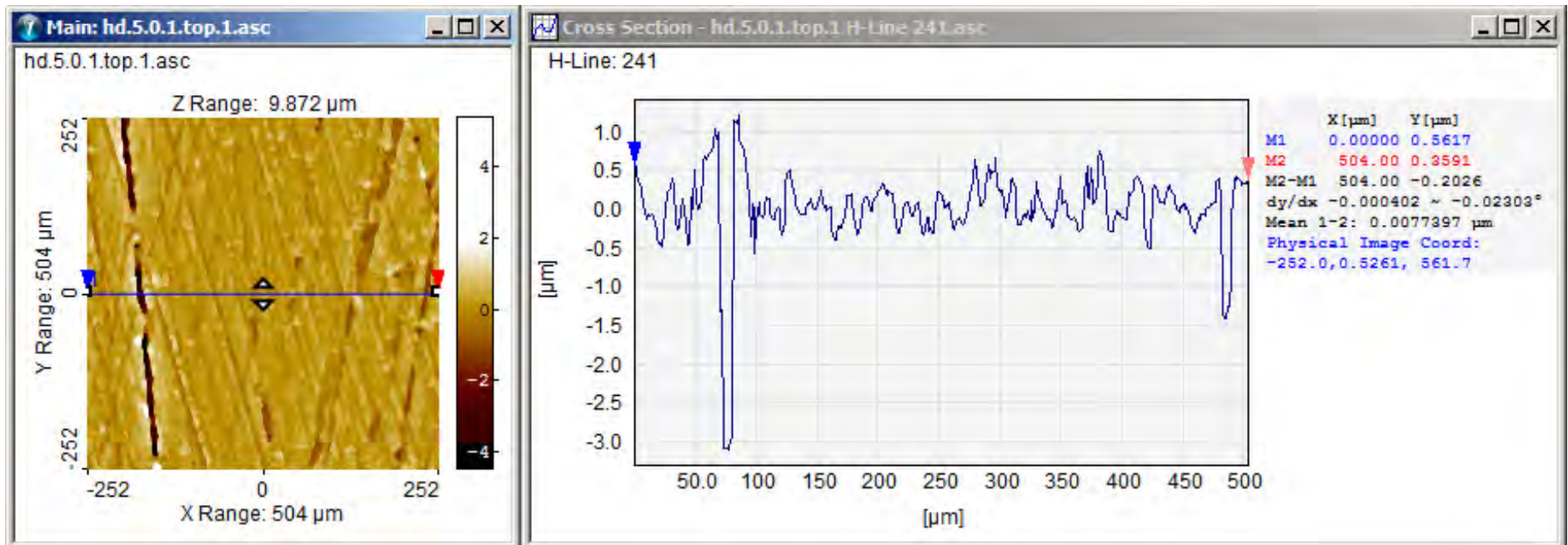
OK Help



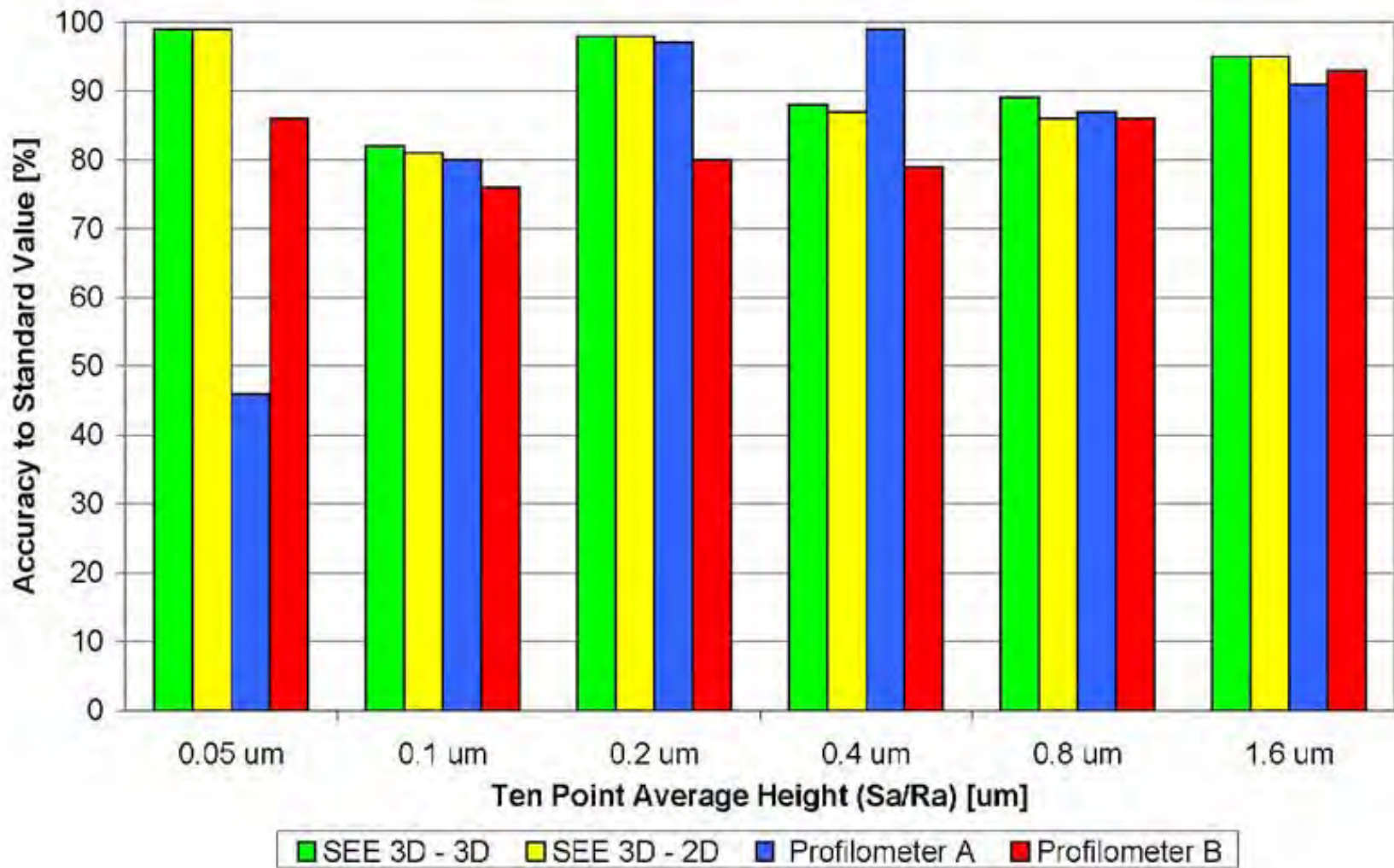
# Line and Form Profiles for 2-D Parameters



# Line and Form Profiles for 2-D Parameters Cast Iron



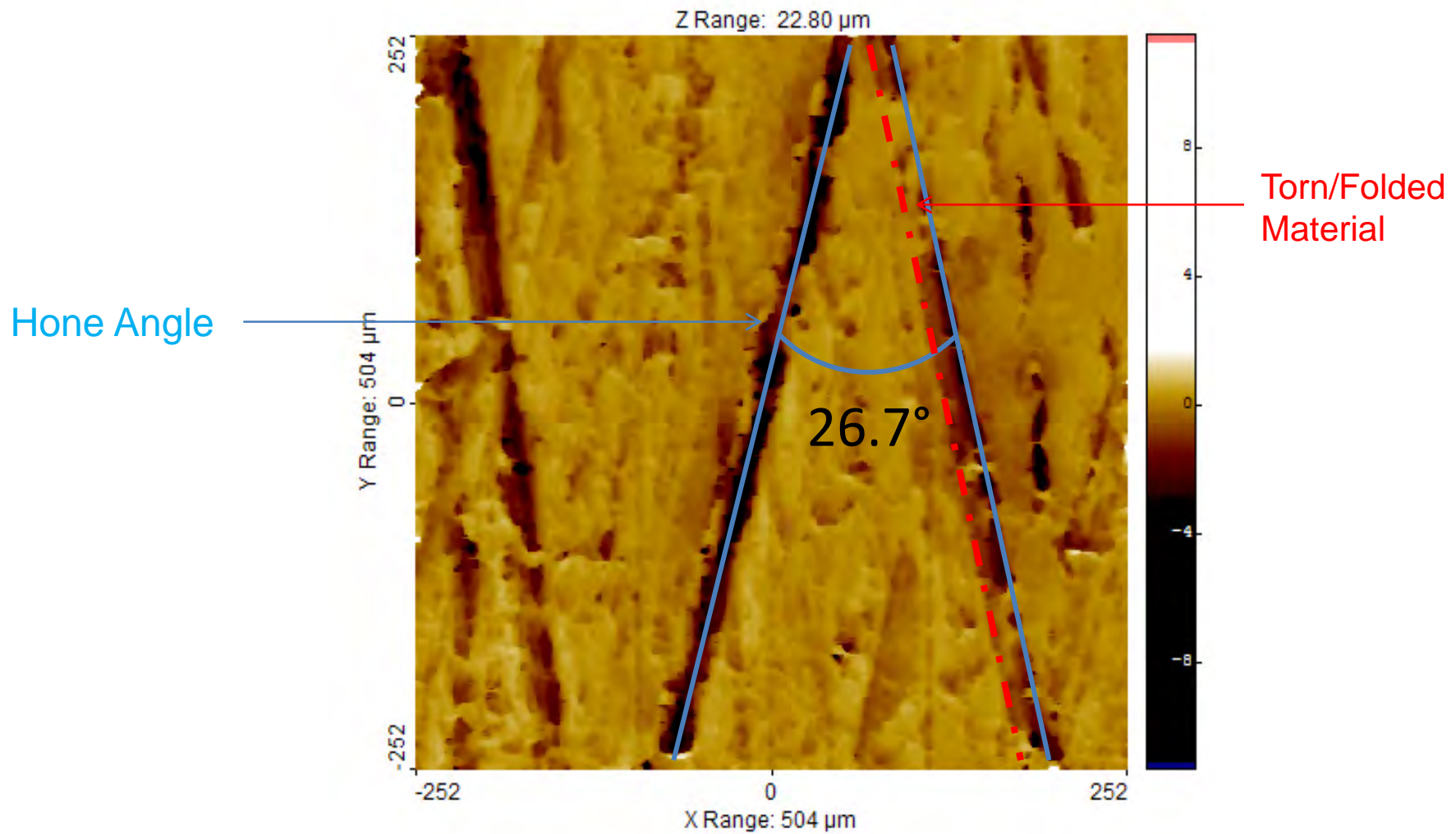
# Accuracy of Various Surface Finish Measuring Equipment





# SEE 3-D INTEGRATED SOFTWARE SYSTEM

Provides Hone Angle and Torn/Folded Material Quantification





# SEE 3-D INTEGRATED SOFTWARE SYSTEM

Provides Quantification of Over 30 Surface Characteristics

Replicate Scan															
	Axial Location	Radial Location	µm								n/a	%	µm <sup>2</sup>		1-10
			R <sub>z</sub>	R <sub>a</sub>	R <sub>vk</sub>	R <sub>k</sub>	S <sub>z</sub>	S <sub>vk</sub>	S <sub>k</sub>	S <sub>pk</sub>	S <sub>cl</sub>	S <sub>dr</sub>	S <sub>2A</sub>	S <sub>3A</sub>	TFM
Cylinder 1	Top	0°	3.62	0.43	1.05	0.89	18.91	1.13	0.82	1.17	0.966	1.70	2.54E+05	2.58E+05	5
		Minor Thrust	2.69	0.40	0.98	0.79	22.48	1.04	0.84	0.79	1.000	1.42	2.54E+05	2.58E+05	6
		180°	2.56	0.27	0.69	0.66	12.10	0.84	0.63	0.75	0.967	0.82	2.54E+05	2.56E+05	5
		Thrust	2.24	0.32	0.74	0.74	15.71	0.92	0.75	0.90	0.980	1.09	2.54E+05	2.57E+05	5
		Average	2.78	0.36	0.87	0.77	17.30	0.98	0.76	0.90	0.978	1.26	2.54E+05	2.57E+05	5.3
		Std. Dev.	0.59	0.07	0.18	0.10	4.44	0.13	0.10	0.19	0.016	0.38	0.00E+00	9.72E+02	0.5
	Mid	0°	7.96	0.78	1.99	1.58	19.80	1.34	1.19	1.12	0.984	2.56	2.54E+05	2.61E+05	5
		Minor Thrust	2.11	0.26	0.50	0.64	25.53	0.86	0.59	1.46	0.804	1.46	2.54E+05	2.58E+05	6
		180°	5.04	0.64	1.99	0.85	31.27	2.16	1.09	3.08	0.606	3.80	2.54E+05	2.64E+05	6
		Thrust	2.17	0.30	0.67	0.58	19.42	0.92	0.97	1.32	0.978	1.78	2.54E+05	2.59E+05	5
		Average	4.32	0.50	1.29	0.91	24.01	1.32	0.96	1.74	0.843	2.40	2.54E+05	2.60E+05	5.5
		Std. Dev.	2.79	0.26	0.82	0.46	5.59	0.60	0.26	0.90	0.179	1.04	0.00E+00	2.64E+03	0.6
	Bottom	0°	4.93	0.46	0.97	0.95	30.12	1.40	1.08	1.51	0.704	3.58	2.54E+05	2.63E+05	5
		Minor Thrust	3.57	0.44	1.00	1.07	29.25	1.36	1.16	2.15	0.907	3.16	2.54E+05	2.62E+05	5
		180°	4.61	0.58	1.28	1.13	21.40	1.37	1.10	1.21	0.912	2.20	2.54E+05	2.60E+05	5
		Thrust	4.89	0.42	0.95	0.90	27.48	1.71	0.98	1.35	0.820	3.63	2.54E+05	2.63E+05	5
		Average	4.50	0.48	1.05	1.01	27.06	1.46	1.08	1.55	0.836	3.14	2.54E+05	2.62E+05	5.0
		Std. Dev.	0.63	0.07	0.16	0.11	3.93	0.17	0.07	0.41	0.097	0.66	0.00E+00	1.68E+03	0.0



# SEE 3-D INTEGRATED SOFTWARE SYSTEM

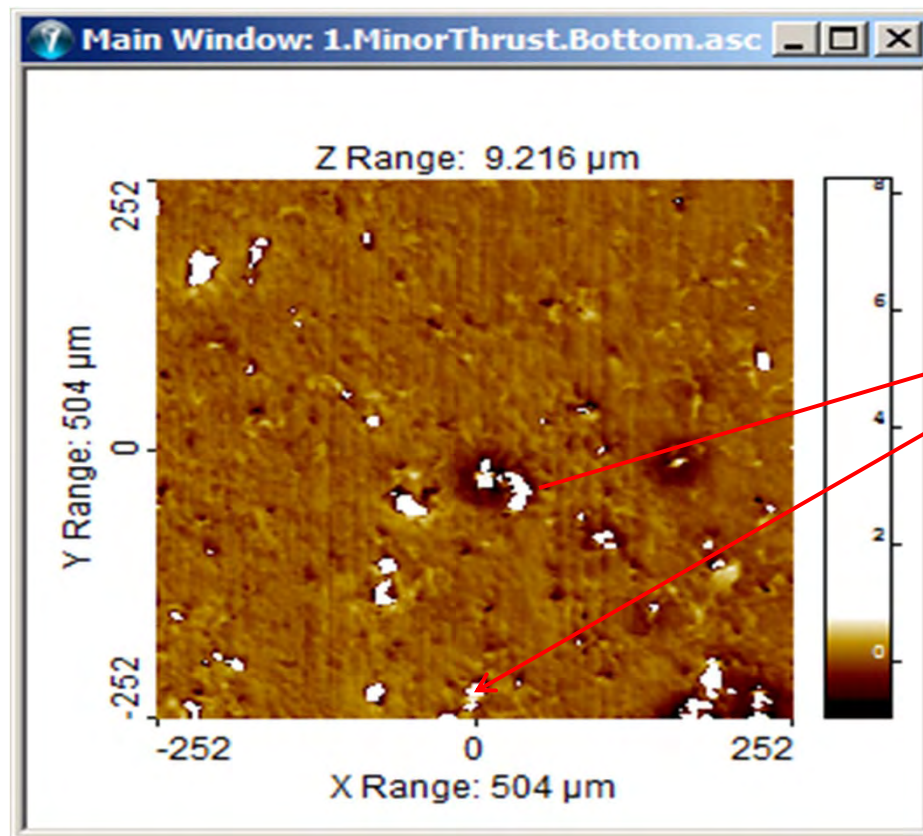
## Provides Optimal Surface Characteristic Specifications

Replicate Scan Cylinder 1						
Axial Location		Top	Mid	Bottom	Purposed Specifications	
μm	$S_z$	17.30	24.01	27.06	8.0	24.0
	$S_{vk}$	0.98	1.32	1.46	0.5	1.2
	$S_k$	0.76	0.96	1.08	0.4	0.8
	$S_{pk}$	0.90	1.74	1.55	0.4	1.5
N/A	$S_{bi}$	0.92	1.10	1.08	0.8	1.5
	$S_{ci}$	0.98	0.84	0.84	0.3	1.0
1-10	TFM	5.3	5.5	5.0	1.0	6.0
Degrees	X-Hatch	25.0	30.6	26.2	25.0	35.0

# SEE 3-D INTEGRATED SOFTWARE SYSTEM

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## Areas of Porosity excluded when SEE 3-D Values are Developed



White represents areas of porosity that are excluded when SEE 3-D finish values are developed.

The resultant data excludes the effect of porosity on reported finish

# SEE 3-D INTEGRATED SOFTWARE SYSTEM

## Coated Liner Average Finish without the Effect of Porosity

Sample 1

Sample 2

Build 34 (Sume) Cylinder Porosity Removed					
Unit	Parameter	Top	Bottom	Purposed Specifications	
μm	S <sub>10z</sub>	2.34	2.08	8.0	24.0
	S <sub>vk</sub>	0.39	0.38	0.5	1.2
	S <sub>k</sub>	0.58	0.35	0.4	0.8
	S <sub>pk</sub>	1.25	0.94	0.4	1.5
N/A	S <sub>bi</sub>	0.23	0.17	0.8	1.5
	S <sub>ci</sub>	1.16	1.08	0.3	1.0

## Coated Liner Average Finish with the Effect of Porosity

Build 34 (Sume) Cylinder with Porosity					
Unit	Parameter	Top	Bottom	Purposed Specifications	
μm	S <sub>10z</sub>	11.45	6.97	8.0	24.0
	S <sub>vk</sub>	1.45	0.69	0.5	1.2
	S <sub>k</sub>	0.68	0.35	0.4	0.8
	S <sub>pk</sub>	1.68	0.84	0.4	1.5
N/A	S <sub>bi</sub>	0.05	0.05	0.8	1.5
	S <sub>ci</sub>	0.56	0.71	0.3	1.0
% SA	Porosity	4.56	2.12	0.0	1.5



# SEE 3-D Two Dimensional Data As Compared to Profilometer Data

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Validation with:

- Gehring
- Sunnen
- Polaris
- Briggs & Stratton
- Caterpillar

