A Brief History of the Development of 2-D Surface Finish Characterization and More Recent Developments in 3-D Surface Finish Characterization

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Presented to SME
Society of Manufacturing Engineers
Honing Clinic
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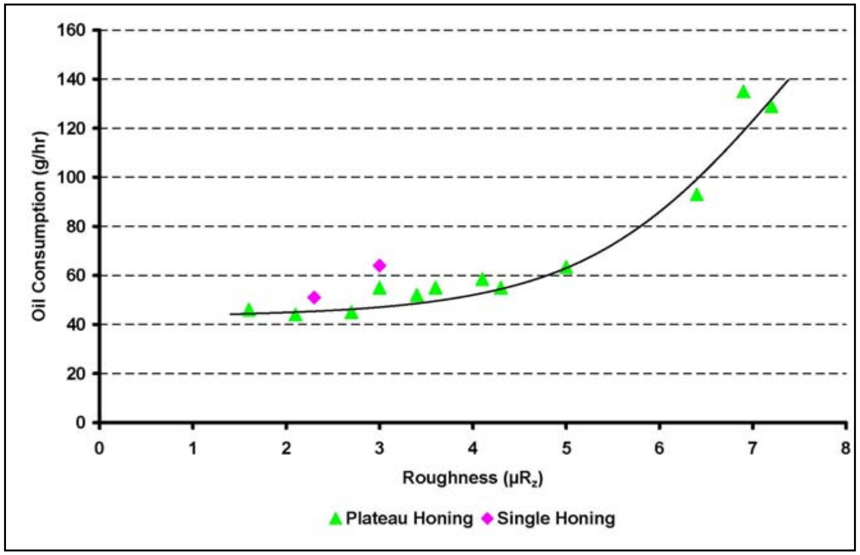
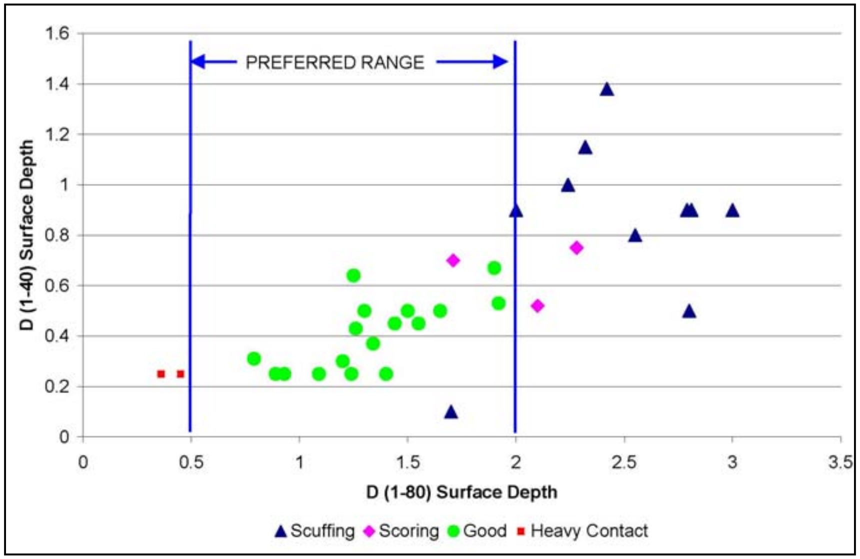
Cylinder Finish Affects . . .

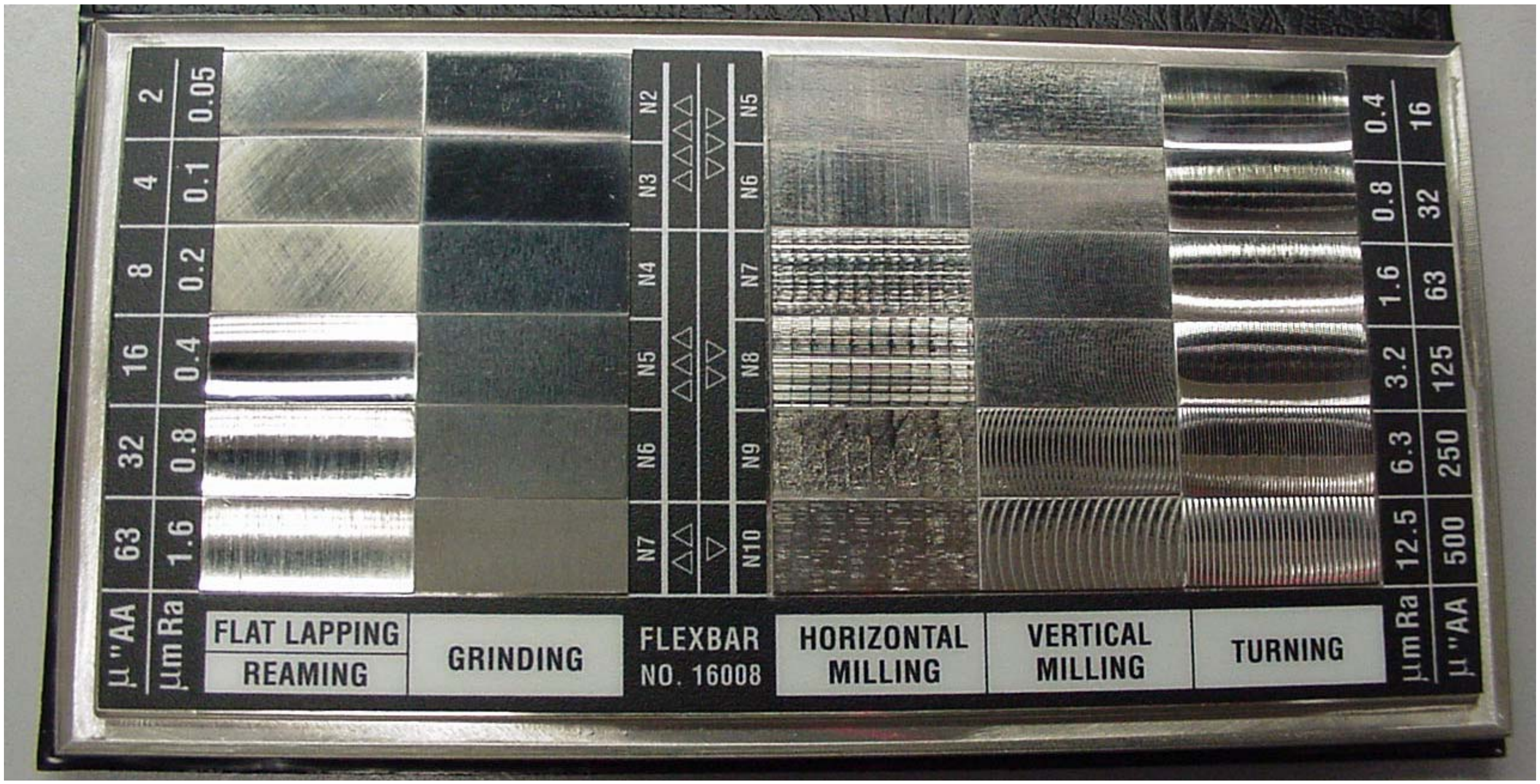
Oil Consumption



Scuff/Wear



Surface Finish Reference Specimens

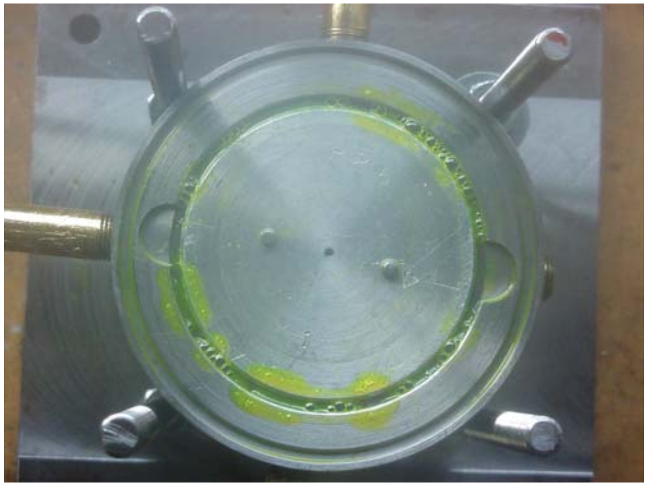


- **Reference by process**
- **Reference by roughness level**

Effect of Finish on Aerosol Flow

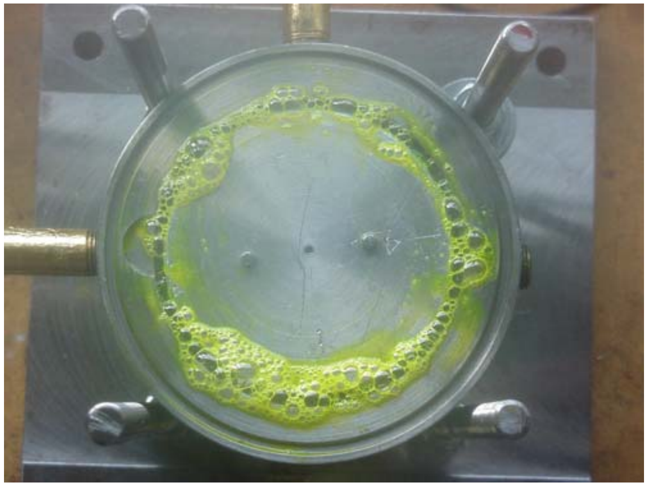
R_{VK} = 20.9 µin

Pressure = 30 psig



R_{VK} = 45.6 µin

Pressure = 30 psig



2-D Finish Parameter Background

- **Needed for finish specifications**
- **2-D parameters in common use**
- **Issues with 2-D finish parameters**

2-D Parameter Development and Country of Origin

Early

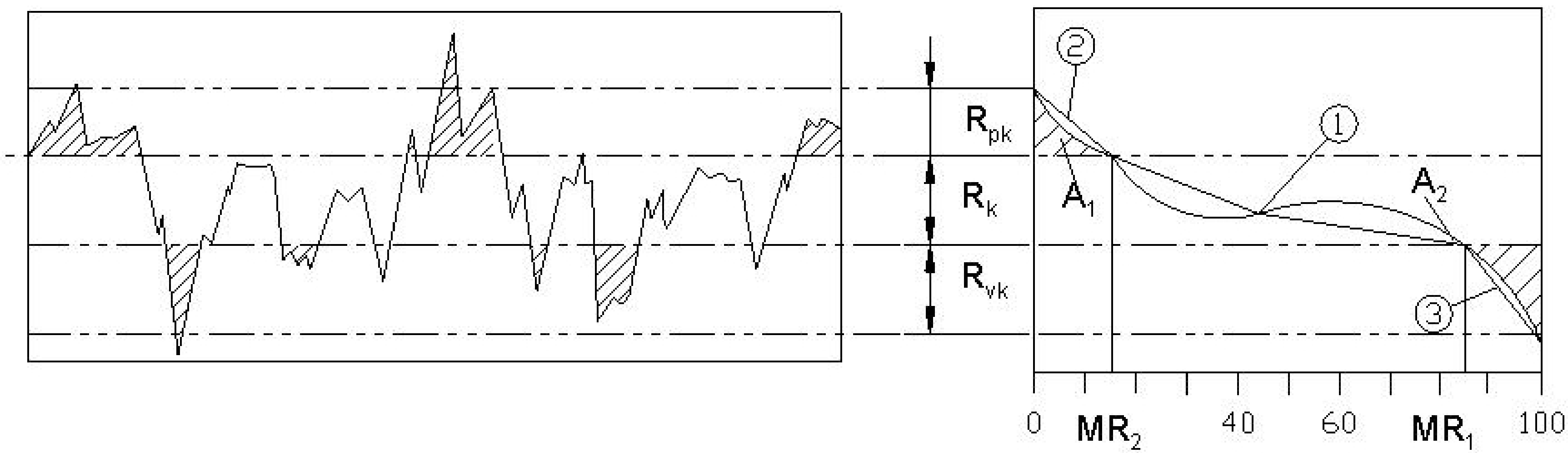
• **England**	**R_A, R_Q**
• **Germany/Russia**	**R_T, R_{TM}, R_Z**
• **Japan**	**R_{SZ} (approximates R_Z)**

Later

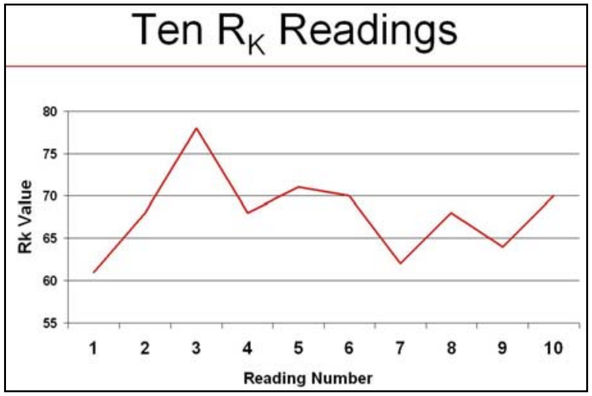
• **Germany**	**R_{PK}, R_K, R_{VK}, M_2**

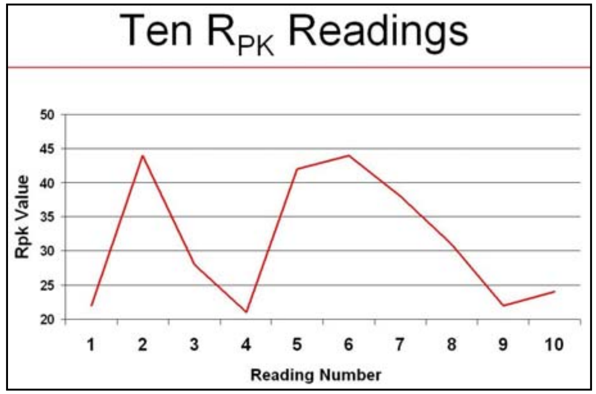
These are parameters commonly utilized for cylinder bore finish; more than 100 parameters have been defined and are available for use.

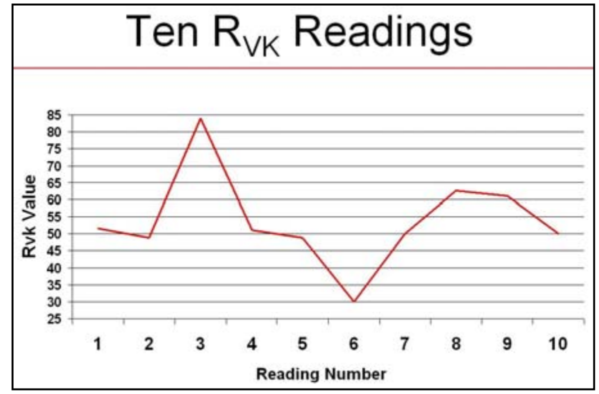
R_{PK}, R_K, R_{VK} Parameter Origin



Inherent Variations





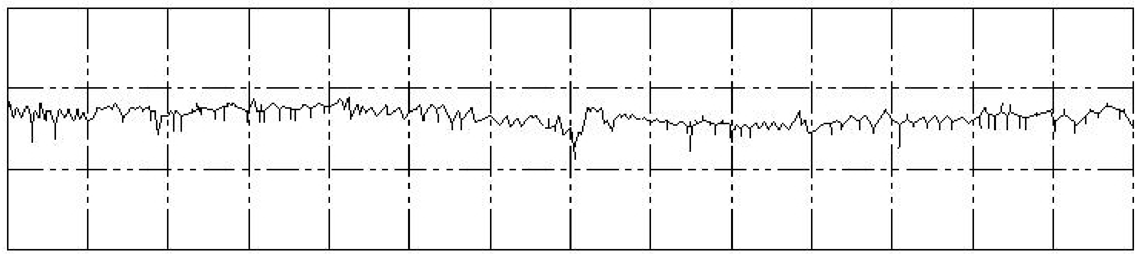


Means to overcome

- **Informal**
  - Make ten readings
  - Discard high/low
  - Average remaining eight readings
- **Formal - ISO 4288 international standard**
  - Discard up to 16% of total readings (readings beyond tolerance limit)

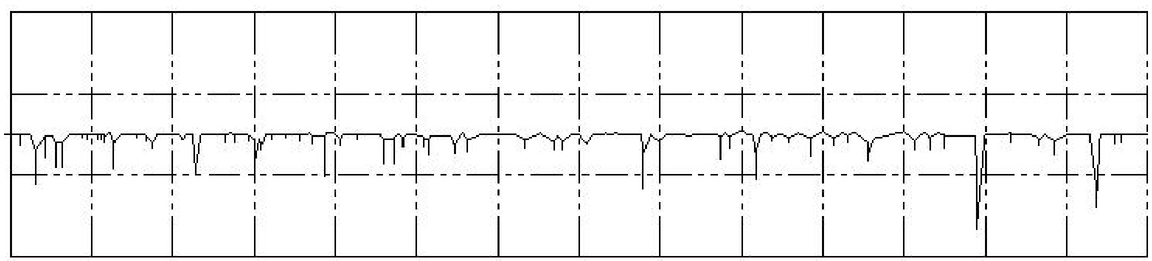
Measured Values for Two Finishes

Surface 1



R_a - 16 µin, R_z = 124 µin, R_k = 50 µin, R_{pk} = 7 µin, R_{vk} = 64 µin

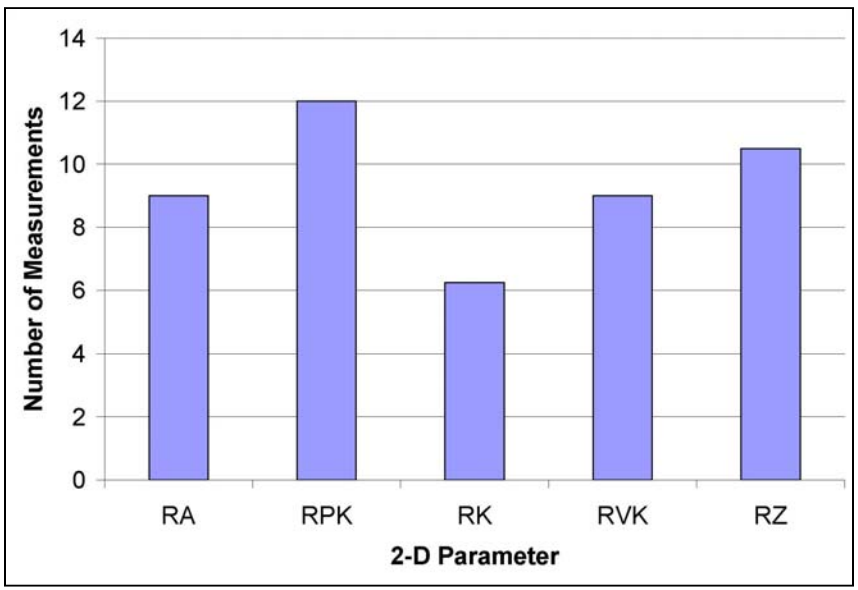
Surface 2

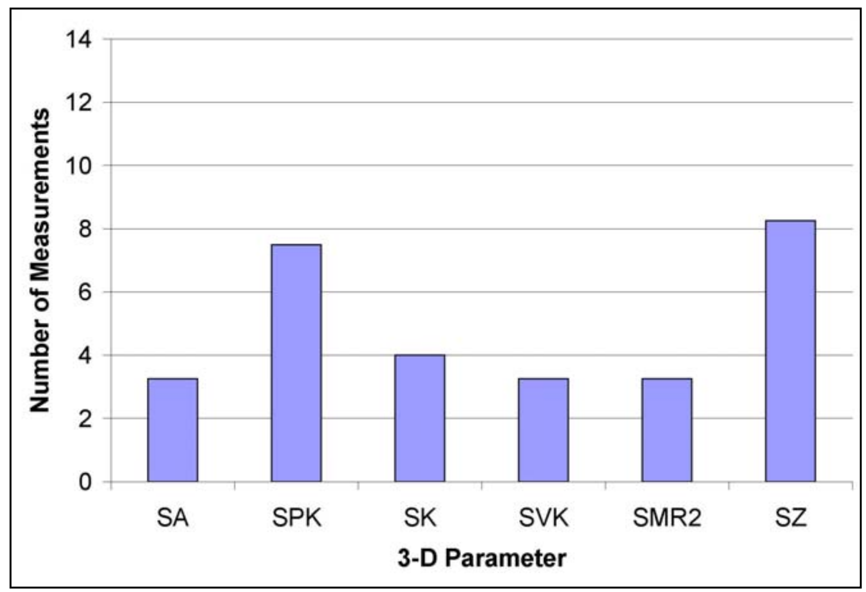


R_a - 16 µin, R_z = 200 µin, R_k = 22 µin, R_{pk} = 2 µin, R_{vk} = 217 µin

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**

Development of 3-D Finish Measurement

- **Software**
  - England
  - France
  - Germany
- **Interferometer**
  - United States
- **Utilization of cylinder bore finish definition**
  - United States

Height Parameters Quantify Z Axis Perpendicular to Surface

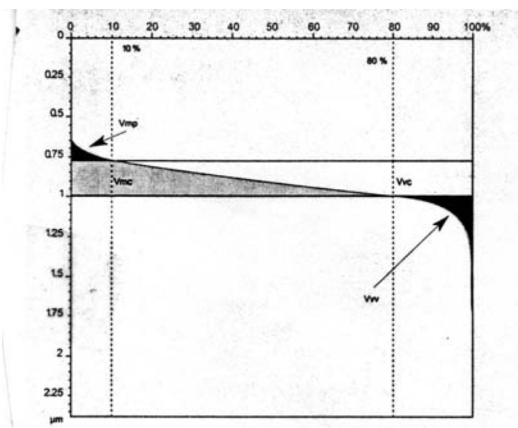
ISO 25178 – New 3-D Finish Standard (to be published)		Din 4776 – Current Related 2-D Parameters	
S_A	Arithmetical mean height (mean surface roughness)	R_A	Arithmetical mean of roughness from the mean line
S_Z	Maximum height – numerical average between the five deepest valleys and the five highest peaks	R_Z	Numerical average height between the five highest peaks and the five deepest valleys within a sampling length
S_P	Maximum peak height – height between the mean plane and the highest plane	R_{PK}	Reduced peak height that will quickly wear away
S_V	Maximum valley height – height between the deepest valley and the mean plane	R_{VK}	Trough depth – provides oil retaining capability
S_K	Core roughness depth – height difference between intersections points of the found least mean square line	R_K	Kernel roughness depth – the long-term running surface that will determine the life of the cylinder

A general relationship exists between 3-D and 2-D finish parameters in the case of height

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	$µm^3/µm$	
V_{MC}	Core material volume of the scale limited surface	$µm^3/µm^2$	
V_{VC}	Core void volume of the scale limited surface	$µm^3/µm^2$	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**



Functional volume parameters Vmp, Vmc, Vvc and Vvv.

Abbott-Firestone Curve

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**
  - **At specific location between top and bottom turn-around**
    Wear µm = $(S_K + S_{PK})$ before test - $(S_K + S_{PK})$ after test

3-D Surface Finish Measurement of Alternative Cylinder Bore Materials

- **Hypereutectic aluminum**
- **Nikasil plating**
- **Thermally applied coatings**

Available 3-D Finish Measurement Information

(Alternate Cylinder Bore Surfaces)

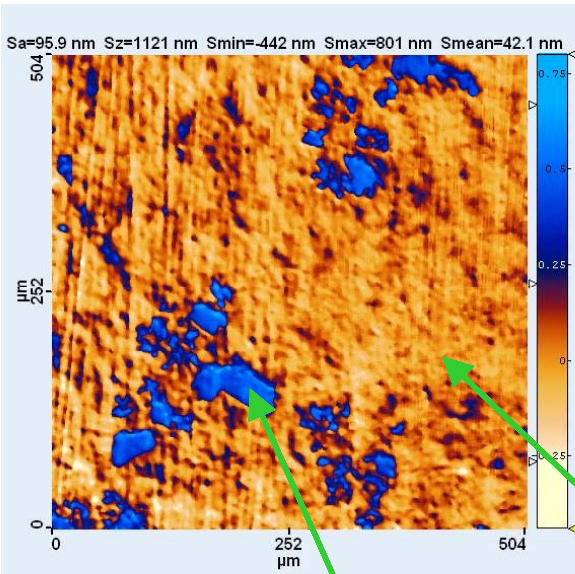
- **2-D surface image (similar to faxfilm) - torn/folded material, crosshatch angle**
- **3-D surface image**
- **2-D/3-D height parameters - S_A/R_A, S_Z/R_Z, S_P/R_{PK}, S_V/R_{VK}, S_K/R_K finish and hard particle height vs. core material**
- **Functional wear parameters - S_{MR} bearing surface area, 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

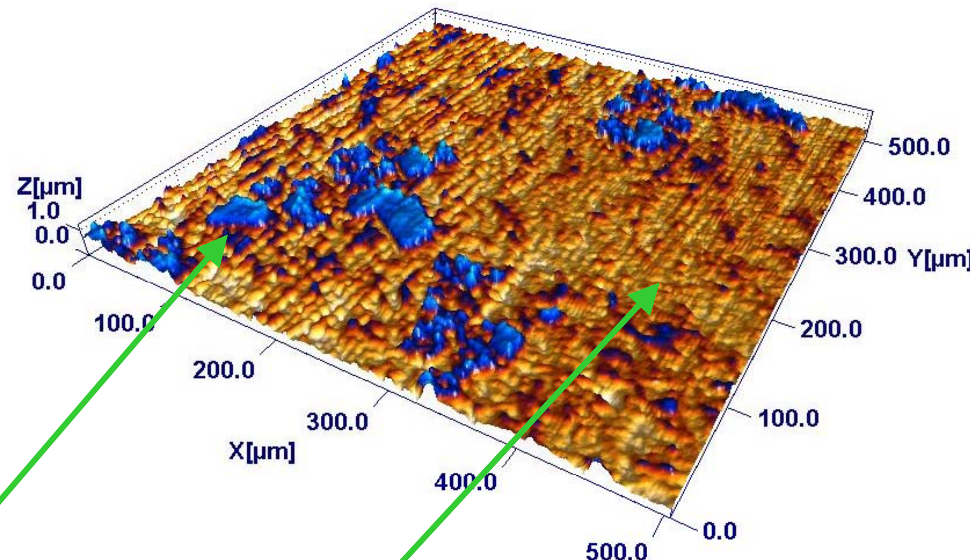
From Top (mm)	3-D Parameters from Replicate Scan (µm)											
	S_A	S_Z	S_{PK}	S_K	S_{VK}	S_{MIN}	S_{MAX}	S_1 ht	% Si	% Pores	S_{bi}	S_{ci}
45	0.082	1.056	0.212	0.222	0.098	-0.508	0.628	1.136	29.7	0.83	0.479	1.820
60	0.083	1.208	0.253	0.215	0.072	-0.436	0.952	1.388	18.4	0.85	0.509	1.760
75	0.103	1.110	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

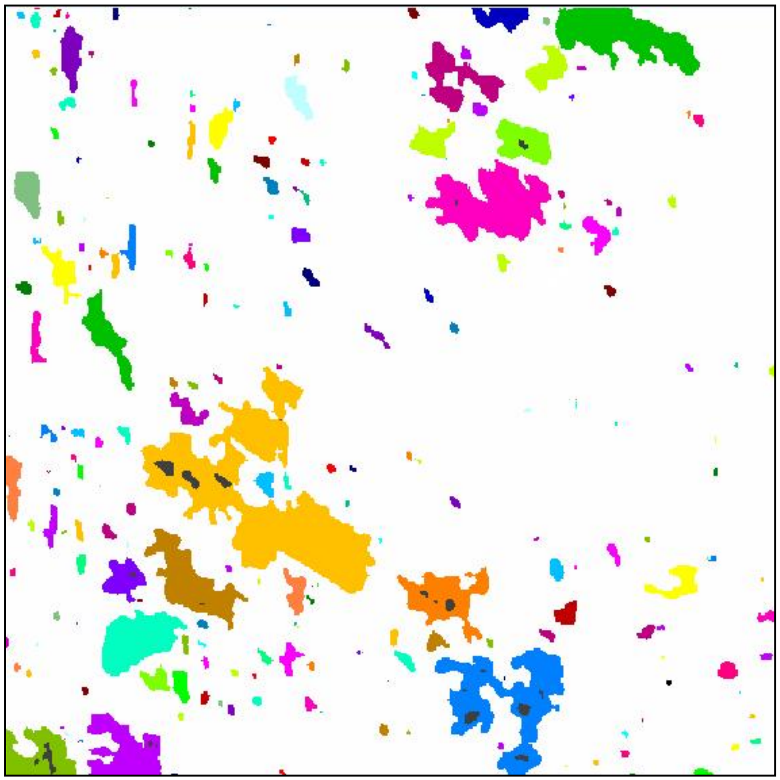


Silicon particle

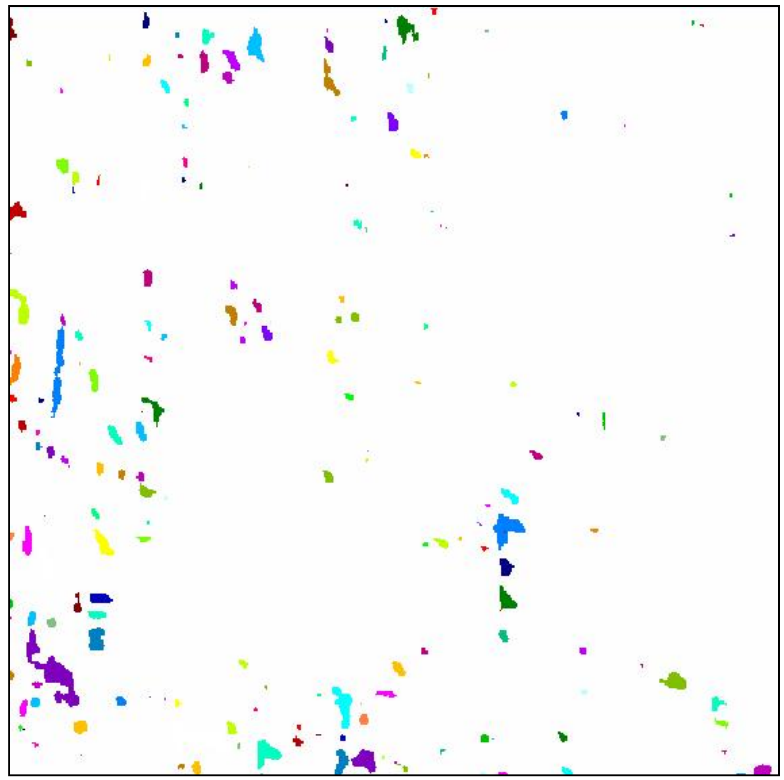
Aluminum matrix

Percent Silicon Particle and Casting Porosity Distribution

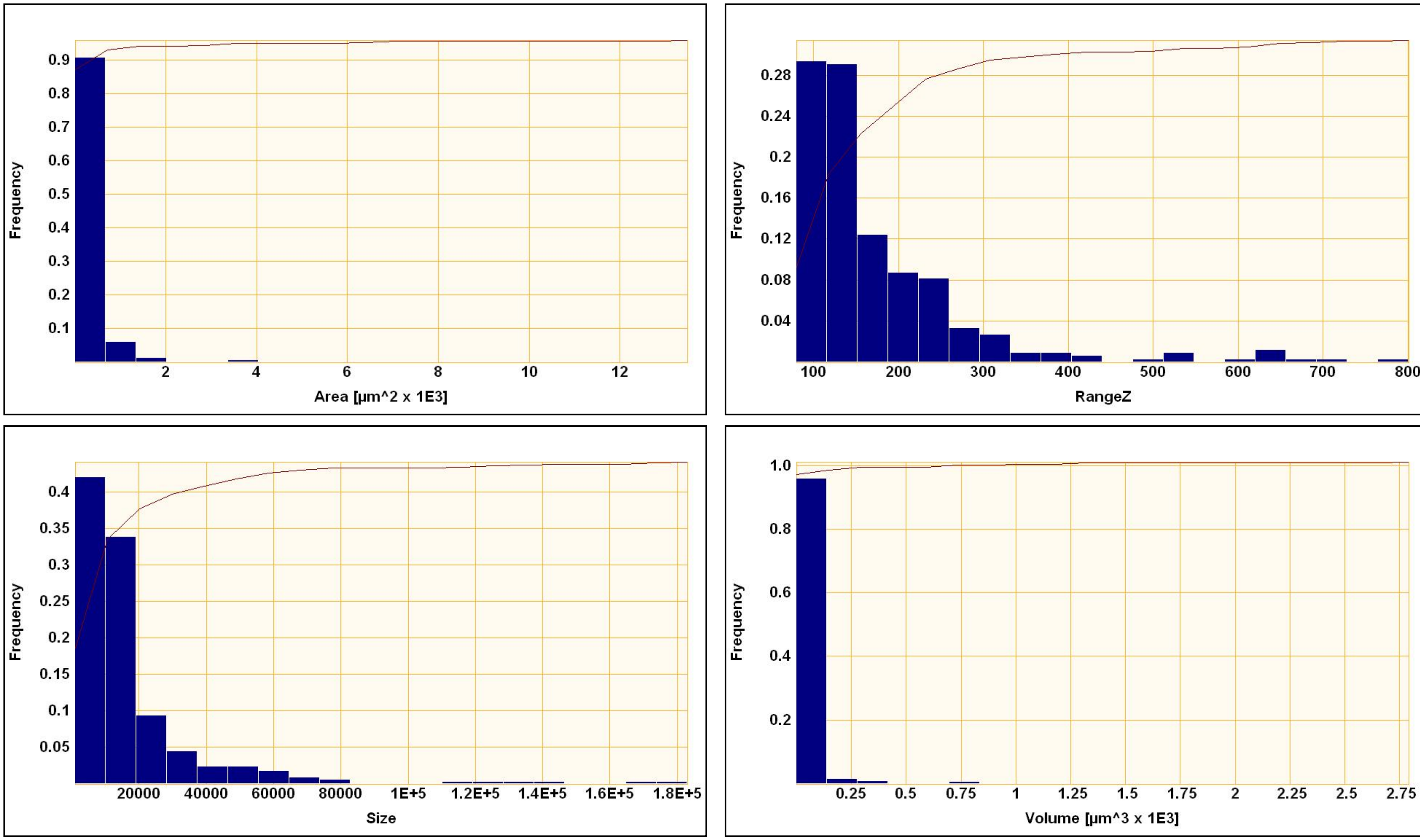
Particle Area at Surface



Porosity Area at Surface



Silicon (Hard) Particle Dimension Data



Available 3-D Finish Measurement Information

(Cast Iron Cylinder Bore Surface)

- **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**
- **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**

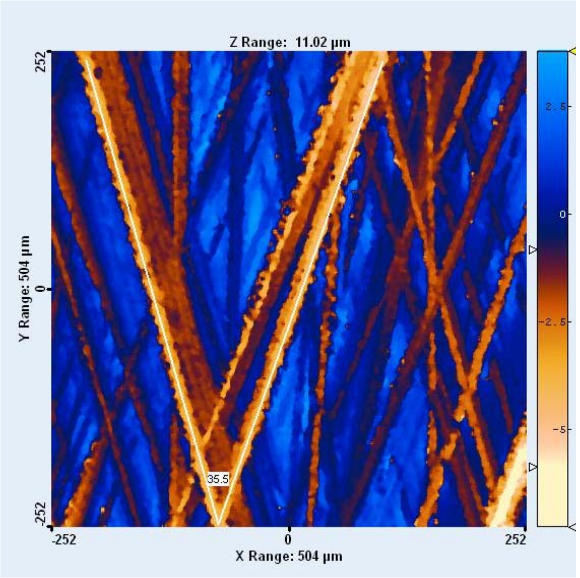
Typical Cast Iron Cylinder Bore Finish Data

(Quantitative Measurement)

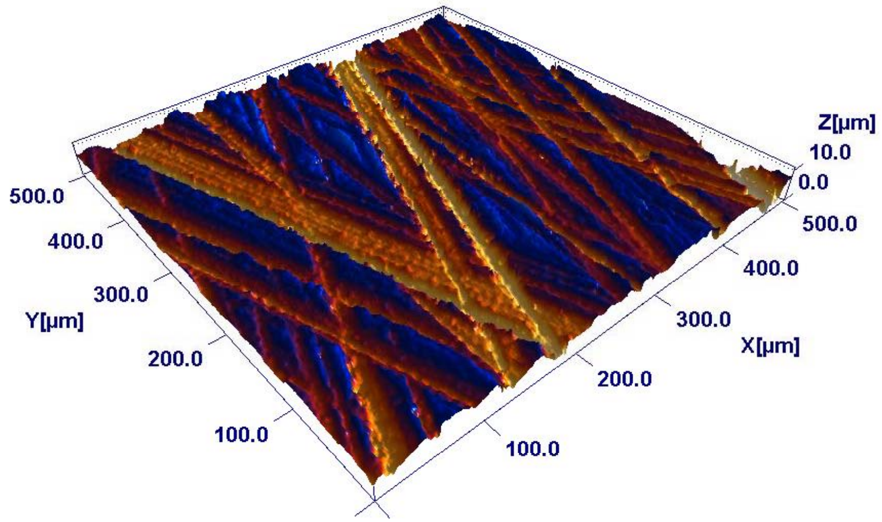
From Top (in)	3-D Parameters from Replicate Scan (µin)									2-D Parameters from Line Profile (µin)			
	S_A	S_{PK}	S_K	S_{VK}	S_{MIN}	S_{MAX}	S_1 ht	S_{bi}	S_{ci}	R_A	R_{PK}	R_K	R_{VK}
0.4	33.504	60.157	86.732	65.394	-187.244	208.346	395.591	32.126	53.937	31.654	86.299	80.315	59.803
1.2	29.370	35.157	90.630	43.228	-232.402	118.701	351.102	24.134	61.417	30.591	47.362	80.433	35.591
2.2	26.220	46.496	68.346	54.606	-144.331	208.937	353.268	30.906	54.331	30.630	63.110	83.740	35.551
3	28.386	45.236	88.268	32.795	-126.496	192.756	319.252	26.102	62.992	29.134	26.772	98.071	33.976
4	31.850	47.559	86.299	46.417	-141.299	183.701	325.000	27.480	58.661	35.118	59.016	98.858	44.764
Average	29.866	46.921	84.055	48.488	-166.354	182.488	348.843	28.150	58.268	31.425	56.512	88.283	41.937
Min	26.220	35.175	68.346	32.795	-232.402	118.701	319.252	24.134	53.937	29.134	26.772	80.315	33.976
Max	33.504	60.157	90.630	65.394	-126.496	208.937	395.591	32.126	62.992	35.118	86.299	98.858	59.803

Typical Cast Iron Cylinder Bore Surface

2-D Image

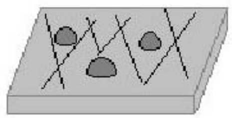


3-D Image



Replication Process

1

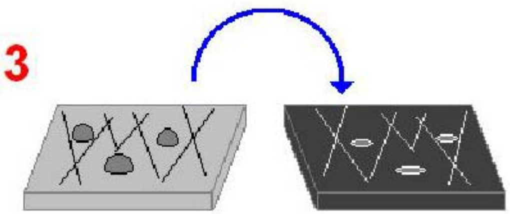


Original honed surface

2

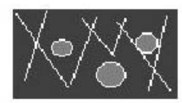
Replicate material cures

3



Replicate material is removed from surface producing a negative copy of the surface

4



Primary software produces 2-D image of replicate surface, similar to Fax Film

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

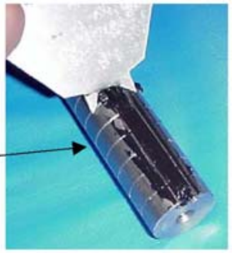
3-D Surface Measurement System Major Components

- **Replicate material**
- **Rod for containing replicate material**
- **Fixture for applying uniform pressure to replicate material and cylinder bore**
- **Interferometer with well-developed software providing 3-D data for the surface, hard particles (if used in bore material coatings), and surface porosity**

Steps in Making Replicate and Acquiring Data

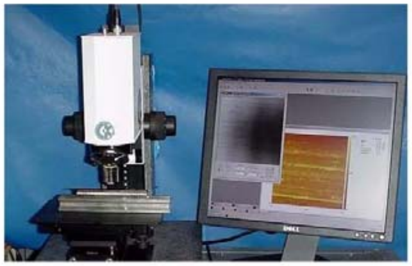
1. Clean specimen surface with lint free cloth and surface cleaning solution e.g. MEK
2. Apply replicating material into rod by slightly overfilling the slot

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)

Accuracy of Various Surface Finish Measuring Equipment