SEE-3D Surface Finish Report

Preliminary Technical Report
TR-359 (generic)

Objective:

To provide a comparison of SEE-3D cylinder finish studies conducted on the XXX customer two cycle sleeve honed with diamond stones and the Hawk Engine Block Honed with vitrified stones.

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Introduction

The CKE SEE-3D cylinder bore surface finish qualification system utilized in this study consists of three components. The first is the SEE-3D replicate head, which is a nondestructive cylinder bore replicating device utilizing a proprietary replicate material to create high resolution molds of the bore surface. The second component to the SEE-3D system is the white light interferometer used to map the surface of the mold in three dimensions. And the third is the customized SPIP software that quantifies up to thirty 2D and 3D surface characteristics. This system allows for quick, accurate and nondestructive cylinder bore surface finish analysis that can be used to control finishing processes and reduce wear and oil consumption in internal combustion engines. The four main steps of the process can be seen in the following images.

Replicate material is dispensed into replicate bar

Replicator head is inserted into bore

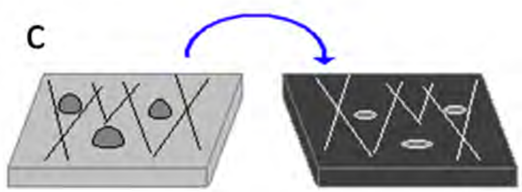
a

Original honed surface

b

Replicate material cures

c



Replicate material is removed, producing a copy of the original surface

SEE-3D replicate is examined with interferometer

3D Images are processed using customized SPIP software to generate surface finish data

The customized SPIP software can quantify a variety of 3D surface finish characteristics (See Table 1) as well as their 2D counterparts. From this large list, eight functional parameters that have been shown to have a strong correlation to oil consumption and wear in cast iron bores are examined and compared to CKE recommendations (See Table 2). These correlations were first determined through research conducted by Dana Corp. and Volvo Corp., detailed in "Cylinder Bore Finishes and Their Effect on Oil Consumption" (Hill, SAE 2001-01-3550, 2001) and "Advanced Techniques for Assessment Surface Topography" (Kogan Page Science, 2003). These correlations have since been validated by years of CKE experience in the field. Additionally, the SEE-3D system can quantify surface porosity size/distribution and surface finish with porosity removed with regards to sprayed coatings, as well as hard particle height/distribution for 390 Aluminum or Nikasil® bores.

Table 1: Possible Surface Finish Parameters Provided by the SEE-3D System

Sa	Sq	Ssk	Sku	Sy	St	Sz	S10z
Sz tph	Sds	Ssc	Sv	Sp	Smean	Sdq	Sdq6
Sdr	S2A	S3A	Sbi	Sci	Svi	Spk	Sk
Svk	Smr1	Smr2	Std	Stdi	Srw	Srwi	Shw
Sfd	Scl20	Str20	Scl37	Str37	Sdc0-5	Sdc5-10	Sdc10-50
Sdc50-95	TFM	X-hatch					

Table 2.1: 3D Functional Surface Finish Parameters Used to Characterize the Bore

CKE Recommended 3-D parameters	Optimal Parameter Range
S_{10z}: Ten Point Height	(Optimal range: 8-24 µm)
S_{vk}: Reduced Valley Depth	(Optimal range: 0.5-1.2 µm)
S_k: Core Roughness Depth	(Optimal range: 0.4-0.8 µm)
S_{pk}: Reduced Peak Height	(Optimal range: 0.4-1.5 µm)
S_{bi}: 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 ≥6, 1-10 scale)
X-Hatch: Hone Cross-hatch angle	(Optimal range: 25-35 Degrees)

Table 2.2: Customer XXX 2D Cylinder Bore Finish Specifications

Finish Parameter	Range (um)
Ra	0.8-2.0
Rmax	5.1-21.6
Rk	1.2-7.1
Rpk	0.3-1.5
Rvk	2.5-6.4
Vo	0.3-0.9
Cylindricity	25 max

Procedure

In this study the CKE SEE-3D system was utilized to quantify the surface characteristics at the top, middle and bottom of the bore in the cylinder (See Figure 1). This was completed by first making replicates at the 0° degree position circumferential location (toward the front of the XXX Engine Block (See Figure 2) using the SEE-3D hardware. 3D mapped images were then taken at the Top, Mid and Bottom axial locations along each replicate utilizing the white light interferometer. Additional images were taken at an area of interest on the Sleeve that had a visually different finish than the surrounding areas. Finally, the mapped images were processed, quantifying critical surface characteristics at each location. The surface characteristics were then compared to the CKE recommended specifications.

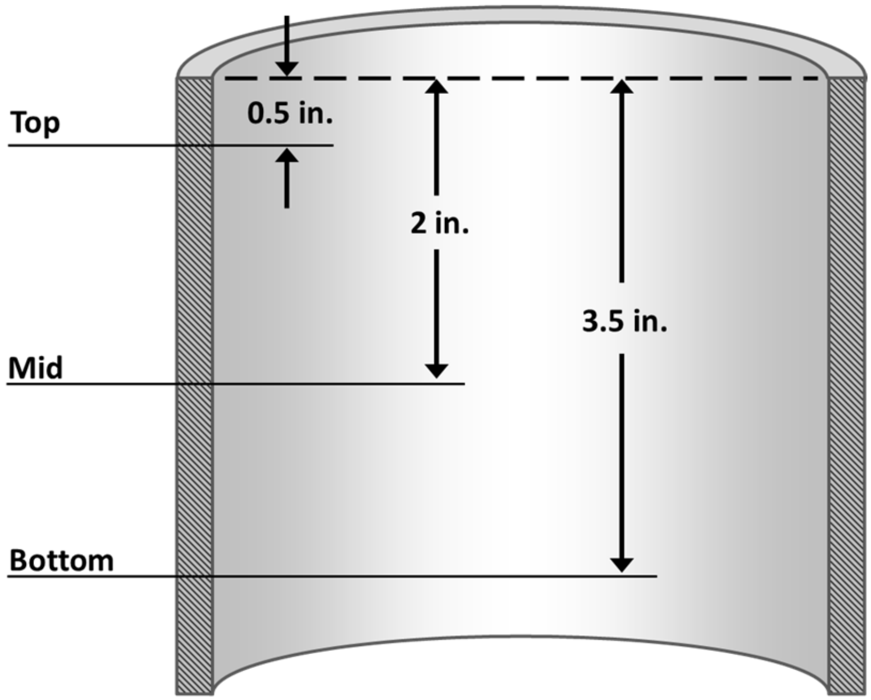


Figure 1: Cylinder Replicate Axial Locations (Sleeve and Engine Block)

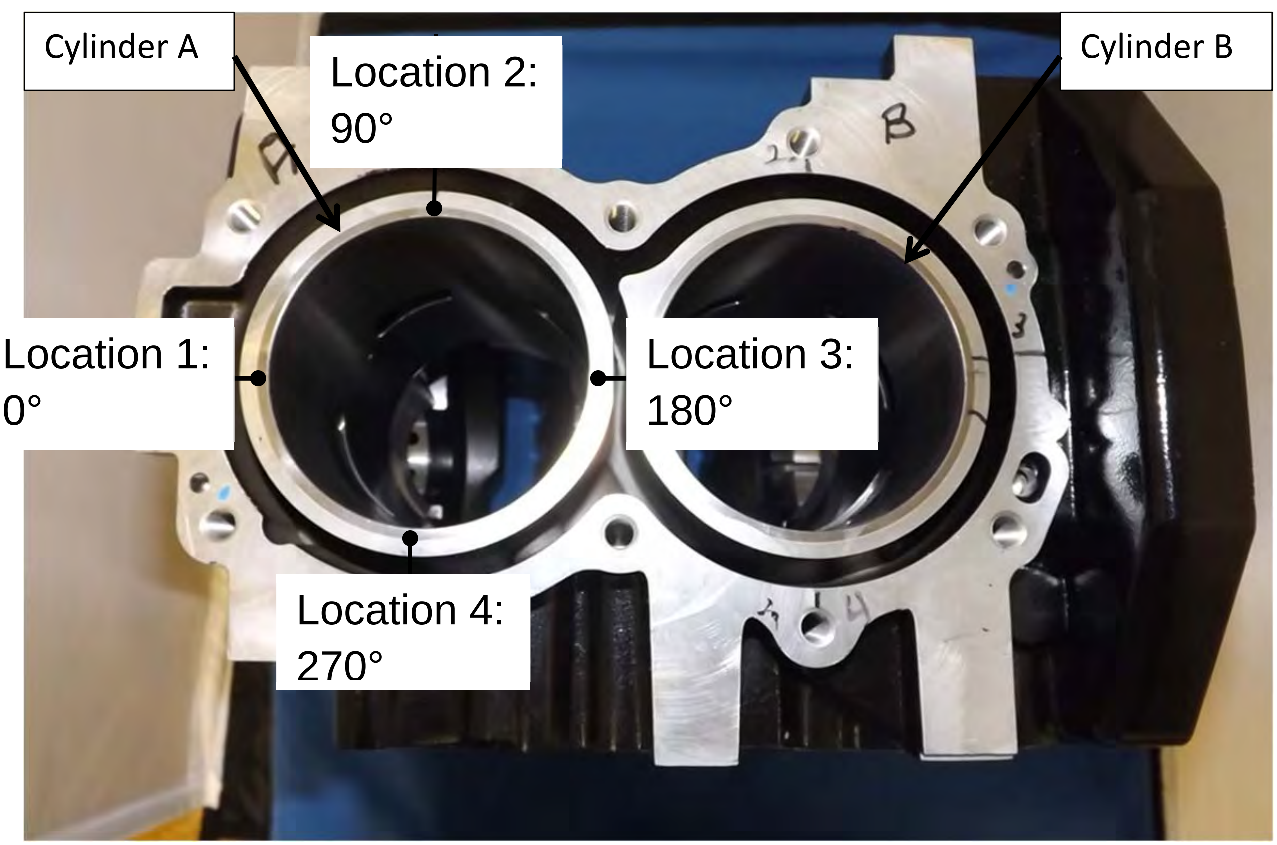


Figure 2: Cylinder Circumferential Replicate Locations

Numbering System

The convention for the CKE image numbering system is as follows:

Sleeve.Circumferential Location.Axial Location.Image Number (convention for Sleeve)

Cylinder.Circumferential Location.Axial Location (Convention for Cylinder Block)

e.g. Image B.1.mid would be Cylinder B, 0° Location, at 2" from the top of the cylinder.

Results

1. Surface Finish Data

1.1. Customer XXX Two Cycle Sleeve Honed with Diamond Stones (originally developed in TR-350). For detailed data see Appendix 359-1.

When looking at the Sleeve, some of the finish values at the axial locations indicate some parameters varying from CKE recommended specifications (Table 2.1 pg. 4). (Values not meeting CKE recommendations are flagged in red and values not meeting Customer XXX Specifications (Table 2.2 pg 4) are flagged in Green)

- Ten Point Height (S_{10z}) is above or at the high end of the CKE recommended specifications for almost all axial locations.
- Reduced Valley Depth (S_{vk}) varies from the CKE recommended values.
- Core Roughness Depth (S_k) varies from the recommendations
- Reduced Peak Height (S_{pk}) varies from the recommended values at most of the axial locations.
- Fluid Retention Index (S_{ci}) is above CKE recommendations at all axial locations.
- Torn and Folded Material (TFM) seems to be controlled well and is at acceptable levels.
- Cross Hatch Angle (X-Hatch) is well above CKE recommended specifications at each axial location and in some cases was hard to quantify as the angles were not consistent.
- Additionally, when visually inspecting the sleeve, an area next to a port on the sleeve (Trans) seemed to have a rough ground finish. The measured surface finish of this area fell outside of CKE recommended specifications for all parameters.

Table 3.1: 3D Surface Finish of Customer XXX Two Cycle Sleeve at Each Location

		Sa	Sq	Sz	S10z	Sci	Spk	Sk	Svk
Two Cycle Sleeve		µm	µm	µm	µm		µm	µm	µm
Sleeve.1.Bot.1.zmp		1.6329	2.0543	28.618	22.999	1.3932	1.2493	5.2863	2.4798
Sleeve.1.Mid.1.zmp		1.487	1.9111	20.944	19.163	1.3186	1.5203	4.6662	3.107
Sleeve.1.Top.1.zmp		1.8871	2.4088	28.575	24.591	1.2177	1.2564	5.4277	3.8741
Sleeve.2.Bot.1.zmp		1.5582	1.9155	25.367	23.327	1.3104	2.4852	4.9822	2.0937
Sleeve.2.Bot.2.zmp		1.8302	2.3197	30.977	28.164	1.3609	1.766	5.9339	2.9402
Sleeve.2.Mid.1.zmp		1.6956	2.1957	27.933	18.226	1.2702	1.703	4.5646	3.5635
Sleeve.2.Top.1.zmp		1.2144	1.5968	23.475	23.009	1.1781	1.1244	3.699	2.4947
Sleeve.2.Trans.1.zmp		1.2105	1.5847	42.153	25.085	1.4291	1.7982	3.8283	1.8728
Sleeve.2.Trans.2.zmp		1.3154	1.9021	33.739	33.179	1.3864	1.9037	3.8506	2.7847

*Above Data from TR-350

Table 3.2: TFM, X-Hatch, and 2D Parameters of Customer XXX Two Cycle Sleeve

Two Cycle Sleeve	TFM Goetze	X-Hatch degrees	Ra µm	Rk µm	Rz µm	R10z µm	Rvk µm
Sleeve.1.Bot.1.zmp	7	N/A	1.2859	3.8	10.513	8.4382	5.8064
Sleeve.1.Mid.1.zmp	6	53	1.5057	4.6	9.8232	8.5675	5.7857
Sleeve.1.Top.1.zmp	8	55.5	1.7703	4.92	11.1	10.369	7.6621
Sleeve.2.Bot.1.zmp	7	N/A	1.759	4.57	13.059	9.8967	8.5531
Sleeve.2.Bot.2.zmp	7	48.6	1.7925	5.06	14.02	12.525	10.032
Sleeve.2.Mid.1.zmp	6	N/A	1.6062	3.47	12.255	10.239	8.6203
Sleeve.2.Top.1.zmp	6	55.8	1.0934	2.9	7.403	6.0063	4.8157
Sleeve.2.Trans.1.zmp	3	49.2	1.247	4.03	9.8643	6.8094	7.3512
Sleeve.2.Trans.2.zmp	3	56.8	1.2223	3.43	8.3536	7.6232	4.7922

*Above Data from TR-350

The surface porosity has been visually observed to be less that 1.5% of the surface which CKE believes is desirable. As the cumulative area of the pores approaches 1.5% of the total area of the surface, oil consumption has been shown to increase. Background at CKE has found that porosity less than 1.5% has little to no effect on oil consumption

From the 3D surface images supplied in Appendix 1 (See Figures 4), it can be seen that the Customer XXX Two Cycle Sleeve has a low amount of torn and folded material content. Figure 4 shows a sample of areas, circled in yellow, from the Customer XXX Two Cycle Sleeve where torn and folded material is present. This material can disrupt proper sealing or act as an abrasive that can lead to premature wear in the engine.

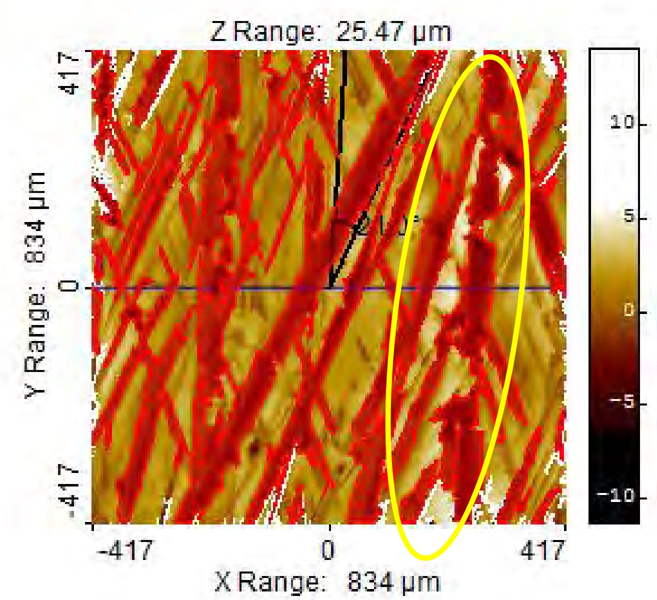


Figure 4: Customer XXX Two-Cycle Sleeve Torn and Folded Material Sample from Appendix 1

1.2. Customer XXX Hawk Engine Block Honed with Vitrified Stones (originally developed in TR-355). For detailed data see Appendix 359-2.

1.2.1. Cylinder A

When looking at Customer XXX Hawk Engine Block Cylinder A, some of the finish values at the axial locations indicate some parameters varying from CKE recommended specifications (Table 2.1 pg. 4). (Values not meeting CKE recommendations are flagged in red and values not meeting Customer XXX Specifications (Table 2.2 pg 4) are flagged in Green)

- Ten Point Height (S_{10z}) varies from the CKE recommended specifications for 1 of the axial locations.
- Reduced Valley Depth (S_{vk}) varies from the CKE recommended specifications for all but 2 of the axial locations.
- Core Roughness (Sk) varies from the recommended values at all axial locations.
- Reduced Peak Height (S_{pk}) is within the recommended values at all of the axial locations.
- Fluid Retention Index (S_{ci}) is above CKE recommendations at all axial locations.
- Torn and Folded Material (TFM) is within or just above acceptable levels.
- Cross Hatch Angle (X-Hatch) is inconsistent and varies from recommendations at many locations.

Table 4.1: 3D Surface Finish of Customer XXX Hawk Engine Block Cylinder A at Each Location

		Sa	Sq	Sz	S10z	Sci	Spk	Sk	Svk
Cylinder A		µm	µm	µm	µm		µm	µm	µm
A.1.bot.zmp		0.63	0.80	9.29	8.92	1.32	0.55	1.89	1.09
A.1.mid.zmp		1.08	1.44	12.22	11.33	1.18	0.99	2.91	2.54
A.1.top.zmp		1.23	1.54	14.78	14.13	1.30	1.01	3.93	1.85
A.2.bot.zmp		0.67	0.85	12.78	9.30	1.15	0.66	1.68	1.37
A.2.mid.zmp		0.90	1.19	12.19	11.63	1.04	0.73	2.24	2.01
A.2.top.zmp		1.18	1.56	12.60	11.51	1.29	1.17	3.08	2.52
A.3.bot.zmp		0.74	0.91	7.57	7.08	1.40	0.65	2.20	1.03
A.3.mid.zmp		0.91	1.17	10.52	9.32	1.09	0.85	2.22	2.05
A.3.top.zmp		1.17	1.47	14.05	13.44	1.31	1.10	3.42	1.84

*Above Data from TR-355

Table 4.2: TFM, X-Hatch, and 2D Parameters of Customer XXX Hawk Engine Block Cylinder A

	TFM	Angle		Ra	Rk	Rz	R10z	Rvk
Cylinder A	Goetze	Degrees		µm	µm	µm	µm	µm
A.1.bot.zmp	5	50.1		0.51	1.19	4.49	3.84	2.48
A.1.mid.zmp	5	53.1		1.30	3.71	7.49	6.87	4.75
A.1.top.zmp	5	45.6		1.06	2.99	5.37	4.92	3.30
A.2.bot.zmp	6	30.8		0.64	1.73	4.13	3.69	2.48
A.2.mid.zmp	5	N/A		1.16	1.68	9.44	7.81	7.02
A.2.top.zmp	6	50.6		1.15	2.84	8.78	7.79	5.48
A.3.bot.zmp	5	59.1		0.80	1.68	6.95	4.84	4.71
A.3.mid.zmp	5	57.3		0.85	1.80	5.95	5.16	3.91
A.3.top.zmp	6	46		1.22	3.58	6.43	5.64	3.45

*Above Data from TR-355

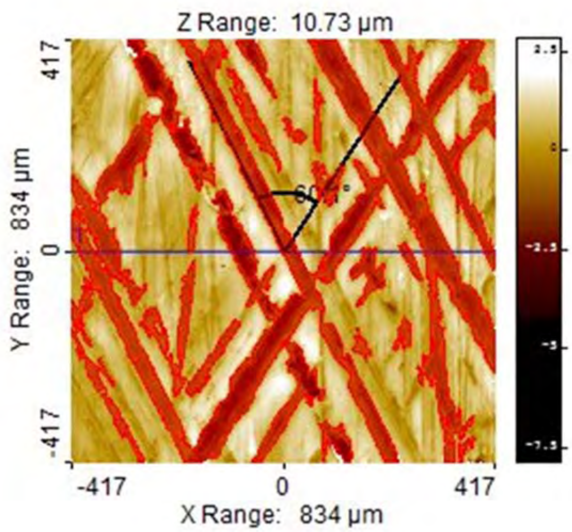


Figure 5: Customer XXX Hawk Engine Block Cylinder A Cross Hatch Angle Example from Appendix 1

1.2.2. Customer XXX Hawk Engine Block Cylinder B

When looking at the Customer XXX Hawk Engine Block Cylinder A, some of the finish values at the axial locations indicate some parameters varying from CKE recommended specifications (Table 2.1 pg. 4). (Values not meeting CKE recommendations are flagged in red and values not meeting Customer XXX Specifications (Table 2.2 pg 4) are flagged in Green)

- Ten Point Height (S_{10z}) is within CKE recommended specifications at most of the axial locations.
- Reduced Valley Depth (S_{vk}) varies from recommendations at most of the axial locations.
- Core Roughness (Sk) varies from the recommended values at all axial locations.
- Reduced Peak Height (S_{pk}) is within the recommended values at all of the axial locations.
- Fluid Retention Index (S_{ci}) is above CKE recommendations at all axial locations.
- Torn and Folded Material (TFM) is within or just above acceptable levels.
- Cross Hatch Angle (X-Hatch) is inconsistent and varies from recommendations.

Table 5.1: 3D Surface Finish of Customer XXX Hawk Engine Block Cylinder B at Each Location

		Sa	Sq	Sz	S10z	Sci	Spk	Sk	Svk
Cylinder B		µm	µm	µm	µm		µm	µm	µm
B.1.bot.zmp		0.80	1.07	9.63	9.44	1.19	0.86	2.14	1.92
B.1.mid.zmp		1.53	1.89	21.30	14.71	1.26	1.69	3.92	2.77
B.1.top.zmp		1.34	1.68	13.74	11.16	1.31	1.19	3.42	2.39
B.2.bot.zmp		0.84	1.04	16.47	14.82	1.44	0.86	2.97	1.07
B.2.mid.zmp		0.93	1.26	16.54	15.38	1.22	0.99	2.48	2.09
B.2.top.zmp		0.86	1.15	11.39	10.73	1.12	0.70	2.08	1.89
B.3.bot.zmp		0.70	0.91	8.92	7.98	1.16	0.69	1.93	1.48
B.3.mid.zmp		0.76	0.98	10.73	9.39	1.10	0.47	1.99	1.54
B.3.top.zmp		1.11	1.36	10.38	9.73	1.38	0.82	3.35	1.47
B.4.bot.zmp		1.05	1.34	13.01	11.66	1.16	0.82	2.72	2.19
B.4.mid.zmp		0.83	1.03	11.08	10.75	1.42	0.72	2.87	1.19
B.4.top.zmp		0.83	1.03	11.08	10.75	1.42	0.72	2.87	1.19

*Above Data from TR-355

Table 5.2: TFM, X-Hatch, and 2D Parameters of Customer XXX Hawk Engine Block Cylinder B

	TFM	Angle		Ra	Rk	Rz	R10z	Rvk
Cylinder B	Goetze	Degrees		µm	µm	µm	µm	µm
B.1.bot.zmp	5	N/A		0.80	2.47	4.94	4.41	2.74
B.1.mid.zmp	6	54.5		1.61	3.24	8.46	8.12	5.68
B.1.top.zmp	5	65.1		1.38	2.97	8.36	7.70	4.91
B.2.bot.zmp	5	N/A		0.88	3.14	3.99	3.82	2.19
B.2.mid.zmp	5	58.7		1.11	2.33	6.82	6.19	4.17
B.2.top.zmp	6	62.1		0.75	2.06	4.24	3.94	2.61
B.3.bot.zmp	6	39.8		0.71	1.73	6.09	5.55	4.56
B.3.mid.zmp	6	60.1		0.85	2.36	5.34	4.73	3.78
B.3.top.zmp	4	N/A		1.18	3.39	6.29	5.79	3.16
B.4.bot.zmp	6	57.5		1.10	2.22	7.00	6.00	4.76
B.4.mid.zmp	5	N/A		0.71	2.17	4.42	3.82	2.94
B.4.top.zmp	6	N/A		0.71	2.17	4.42	3.82	2.94

*Above Data from TR-355

Images that List an “N/A” in the X-Hatch table show uneven hone-lines.

Comparison:

Below is a comparison of Customer XXX Two Cycle Sleeve and XXX Hawk Engine Block Cylinders A and B. Red bars bracket CKE recommended specification (Table 2.1 pg. 4) range for the parameter. Green Bars bracket Customer XXX 2D surface finish specification (Table 2.2 pg. 4).

Most axial locations are within CKE recommendations.

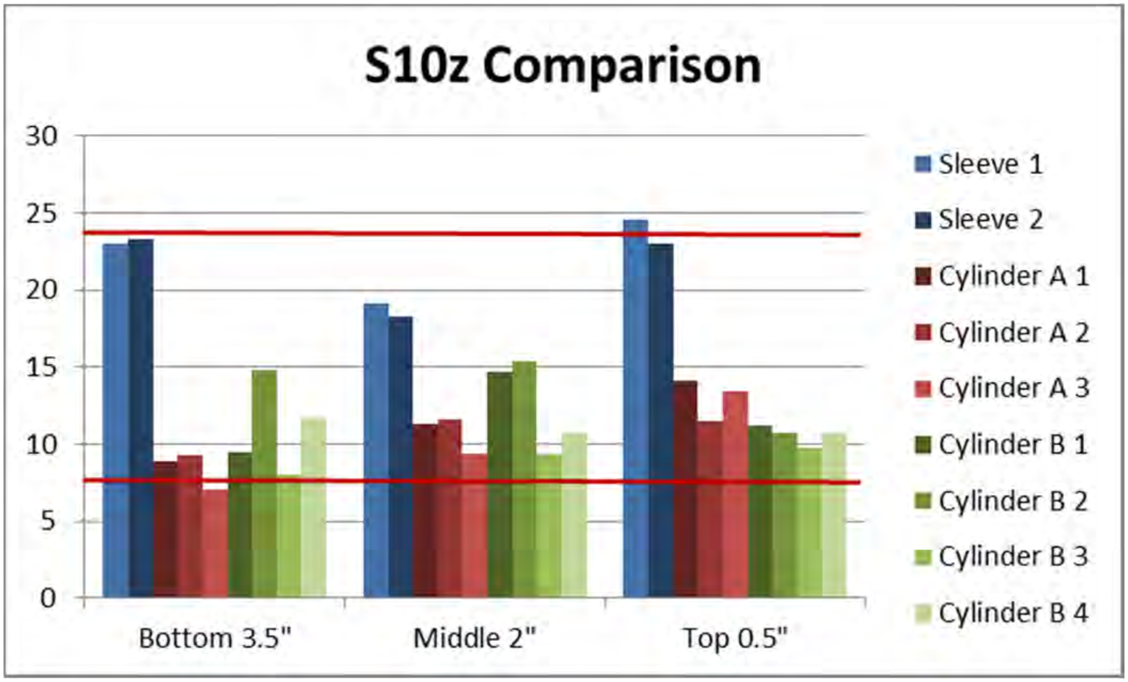


Figure 6.1: Comparison of S_{10z} between the three bores

The Sleeve was found to have a higher S10z value than the engine block.

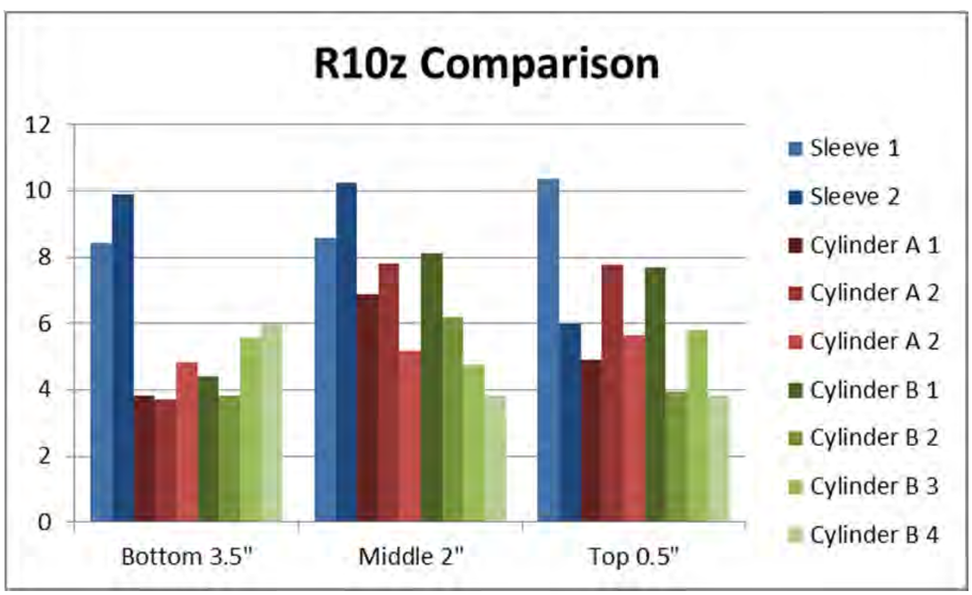


Figure 6.2: Comparison of R10z between the three bores

Most axial locations are above the recommendations

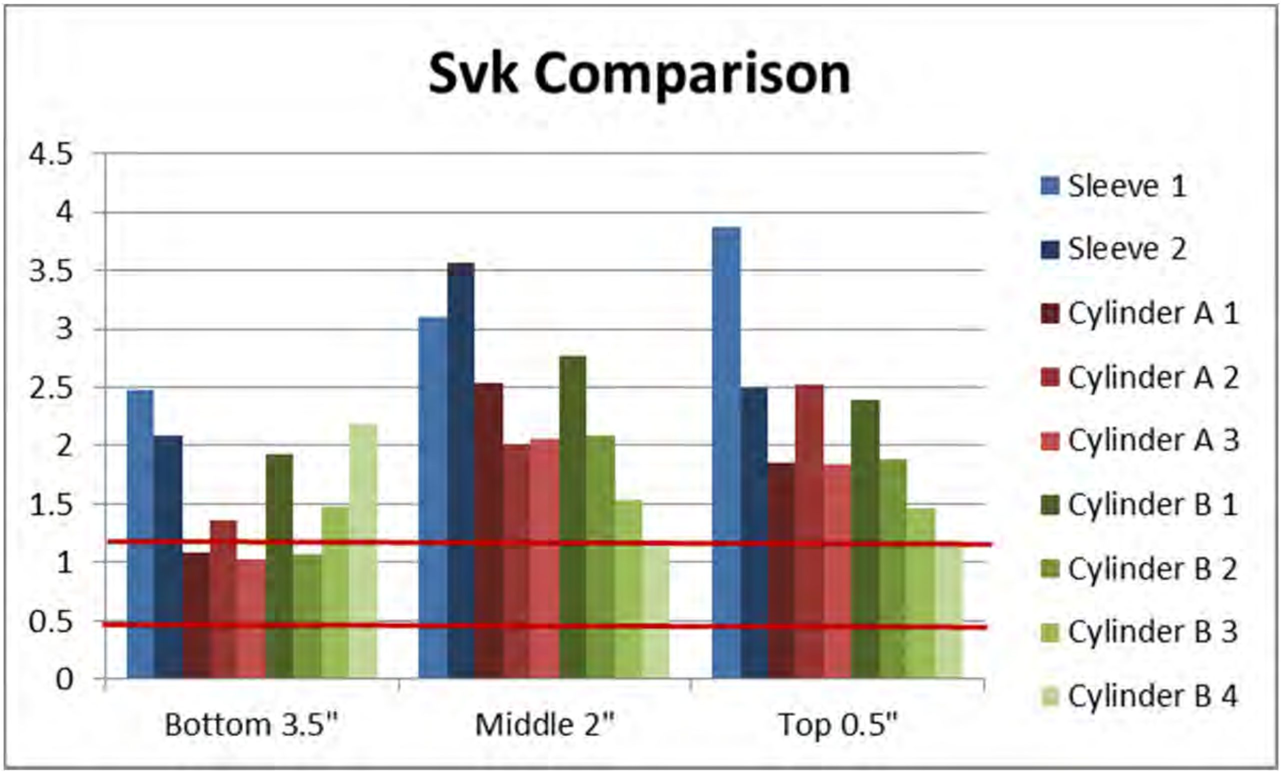


Figure 7.1: Comparison of S_{vk} between the three bores

The Svk values tend to be greater in the Sleeve than in the Engine Block.

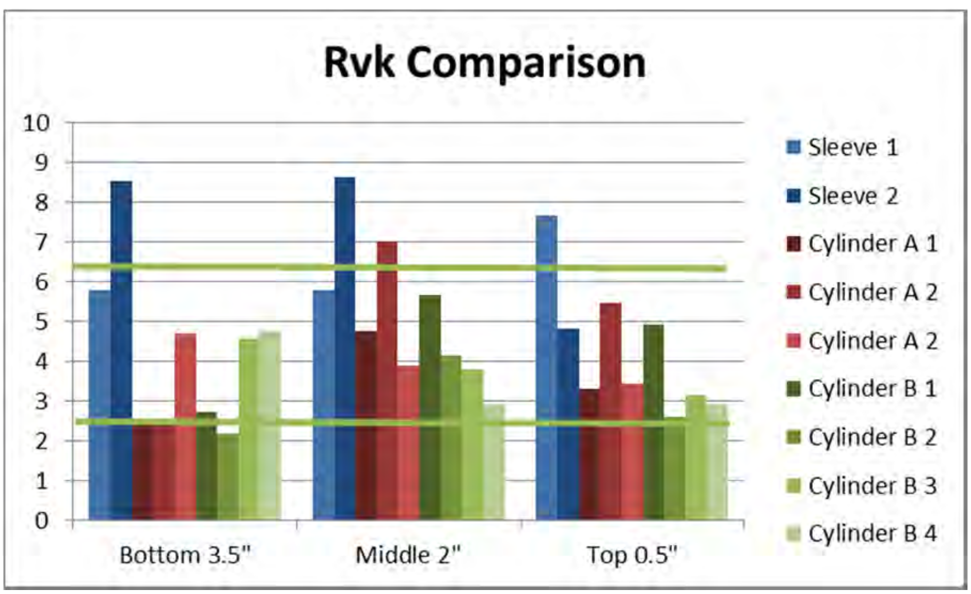


Figure 7.2: Comparison of Rvk between the three bores

All three blocks exhibit Core Roughness values above the recommendations

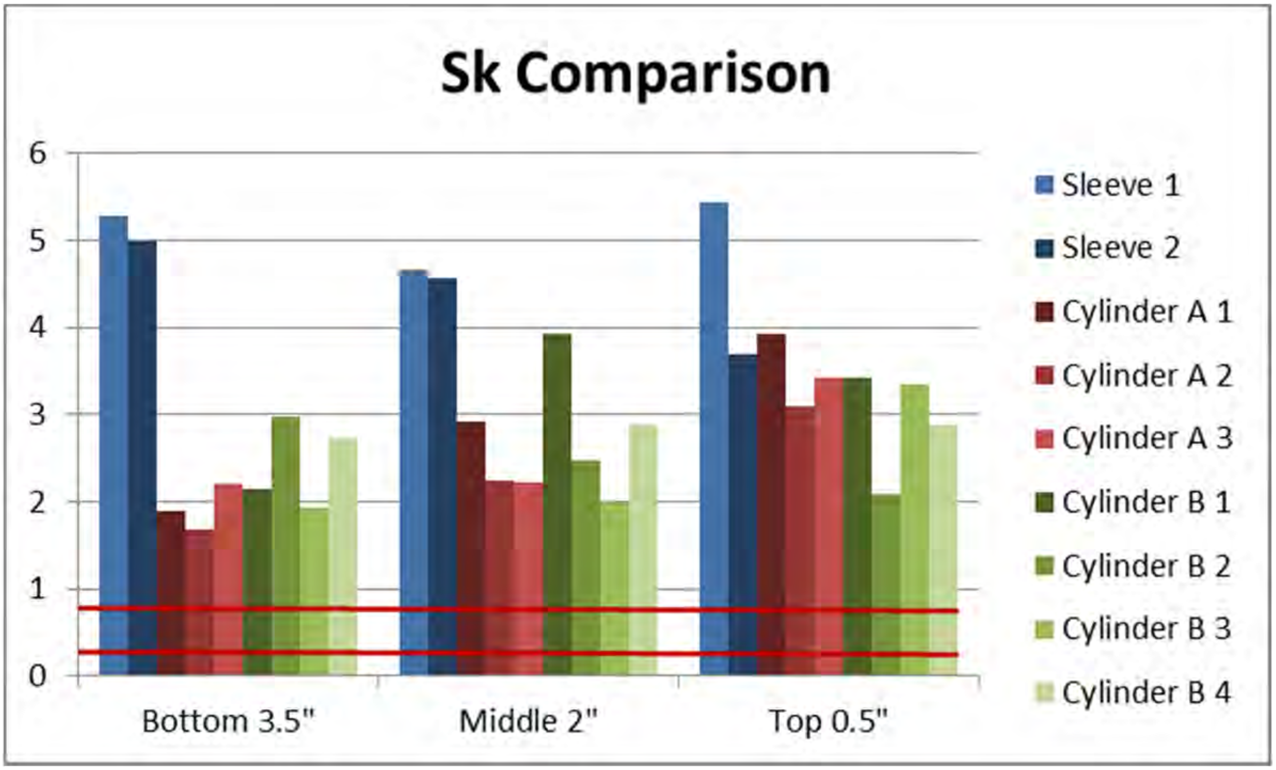


Figure 8.1: Comparison of S_k between the three bores

The sleeve consistently has higher Sk values than the engine block.

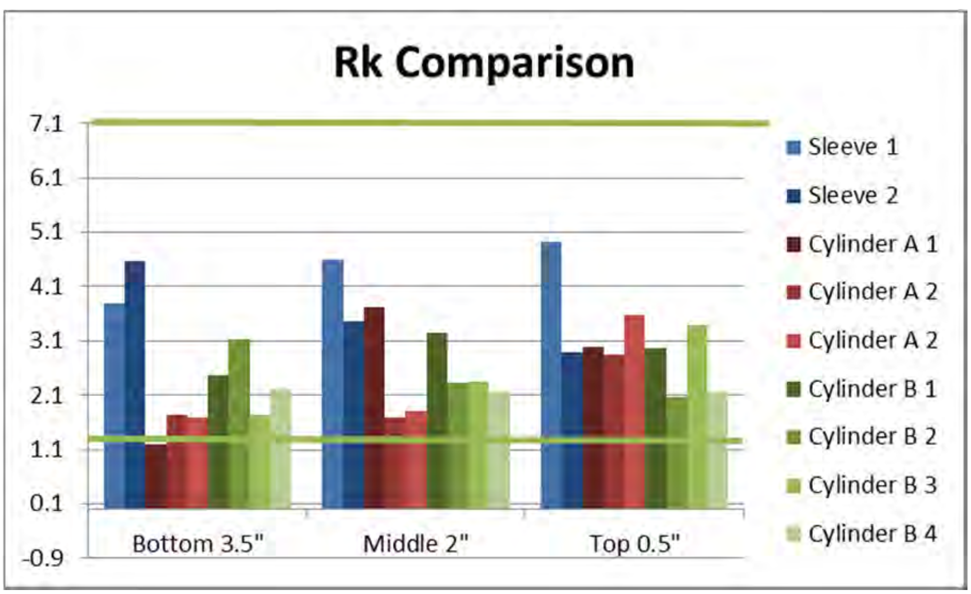


Figure 8.2: Comparison of Rk between the three bores

The three blocks are within or to the high end of the recommended values.

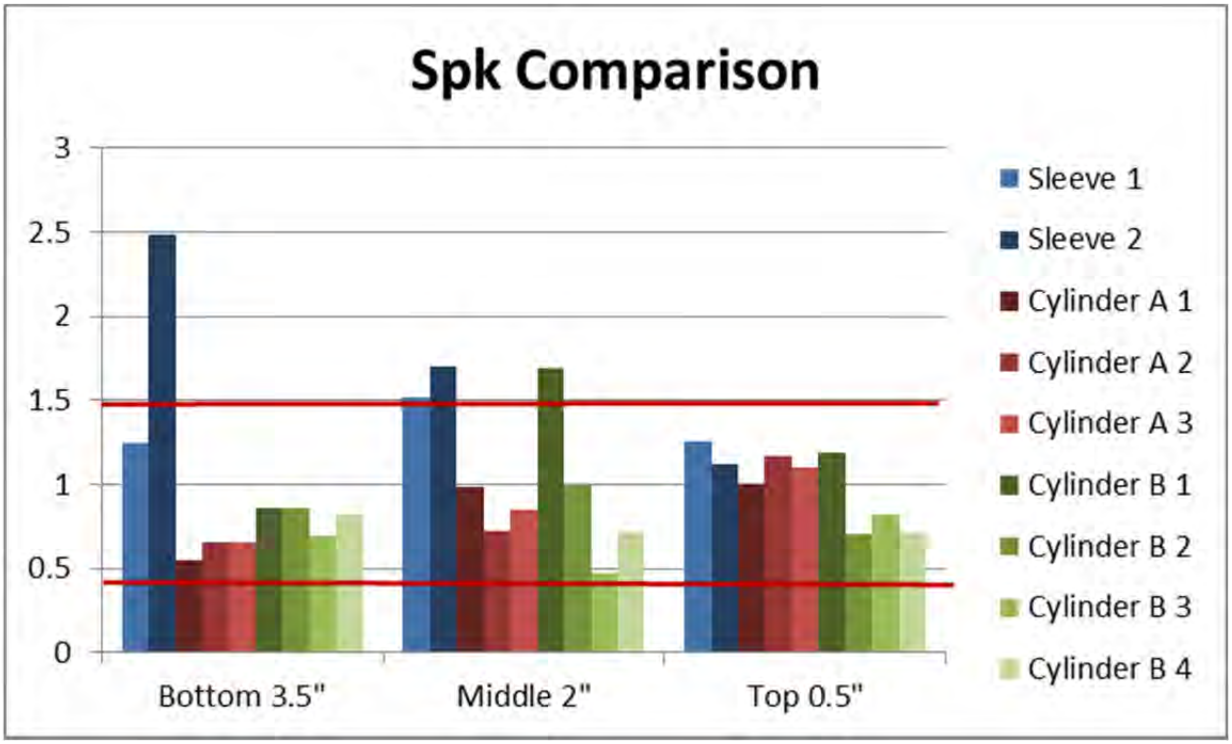


Figure 9.1: Comparison of S_{pk} between the three blocks

At the bottom and the middle locations, the sleeve has greater Spk values. At the top location, the sleeve and the engine block have very similar values.

All blocks have values that are to the high end of the recommendations

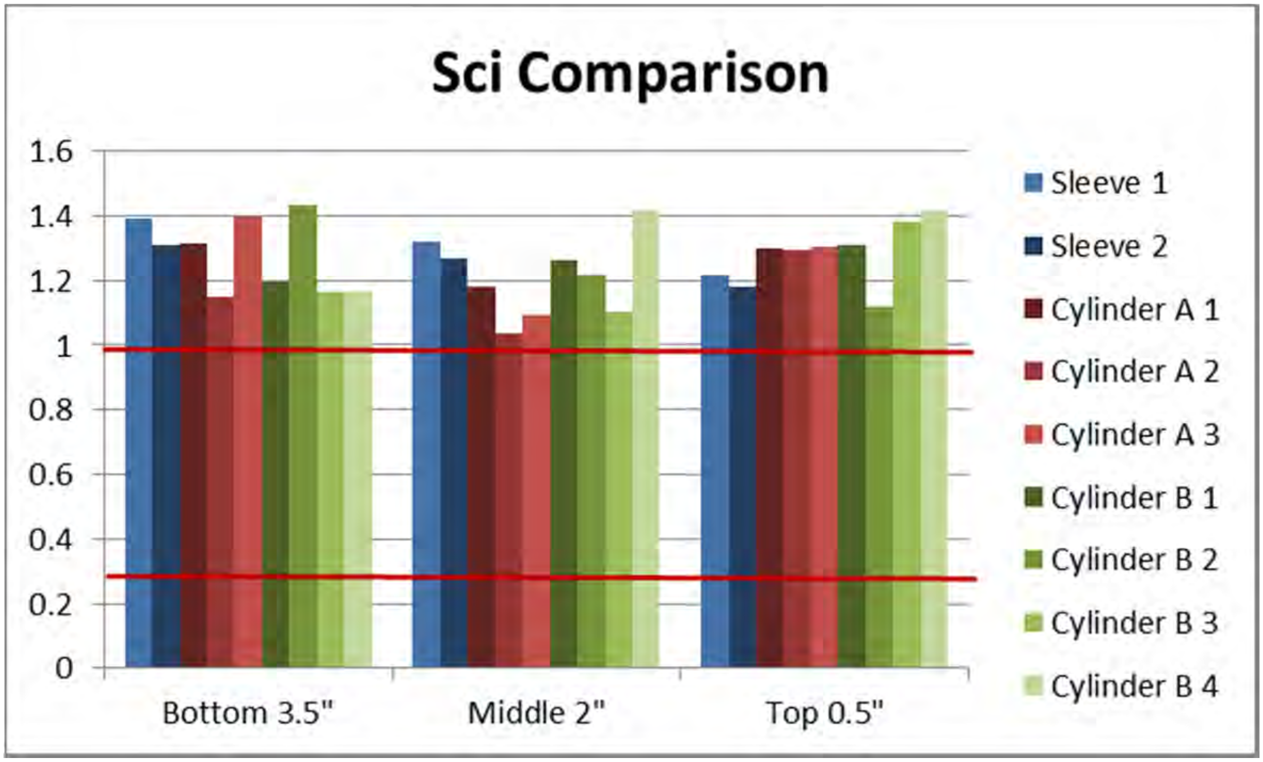


Figure 11: Comparison of S_{ci} between the three blocks

The sleeve and the engine block both have consistent Sci values

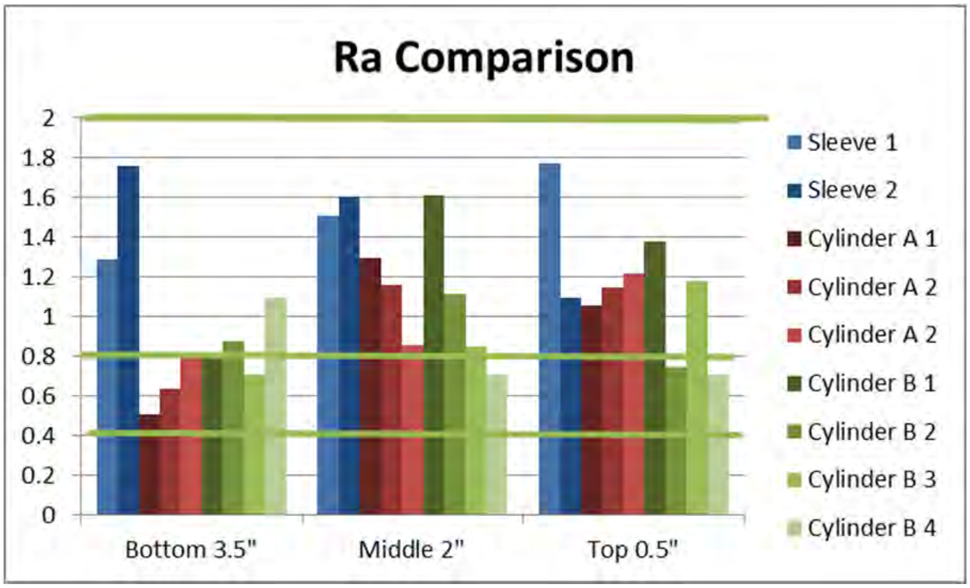


Figure 12.1: Comparison of Ra between the Bores

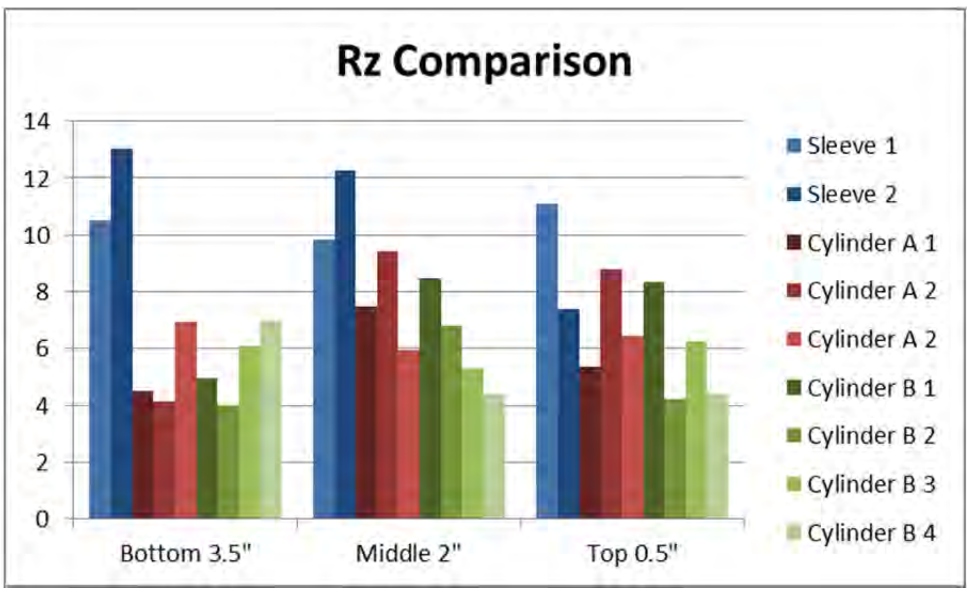


Figure 12.2: Comparison of Rz between the Bores

All locations are within or near recommendations

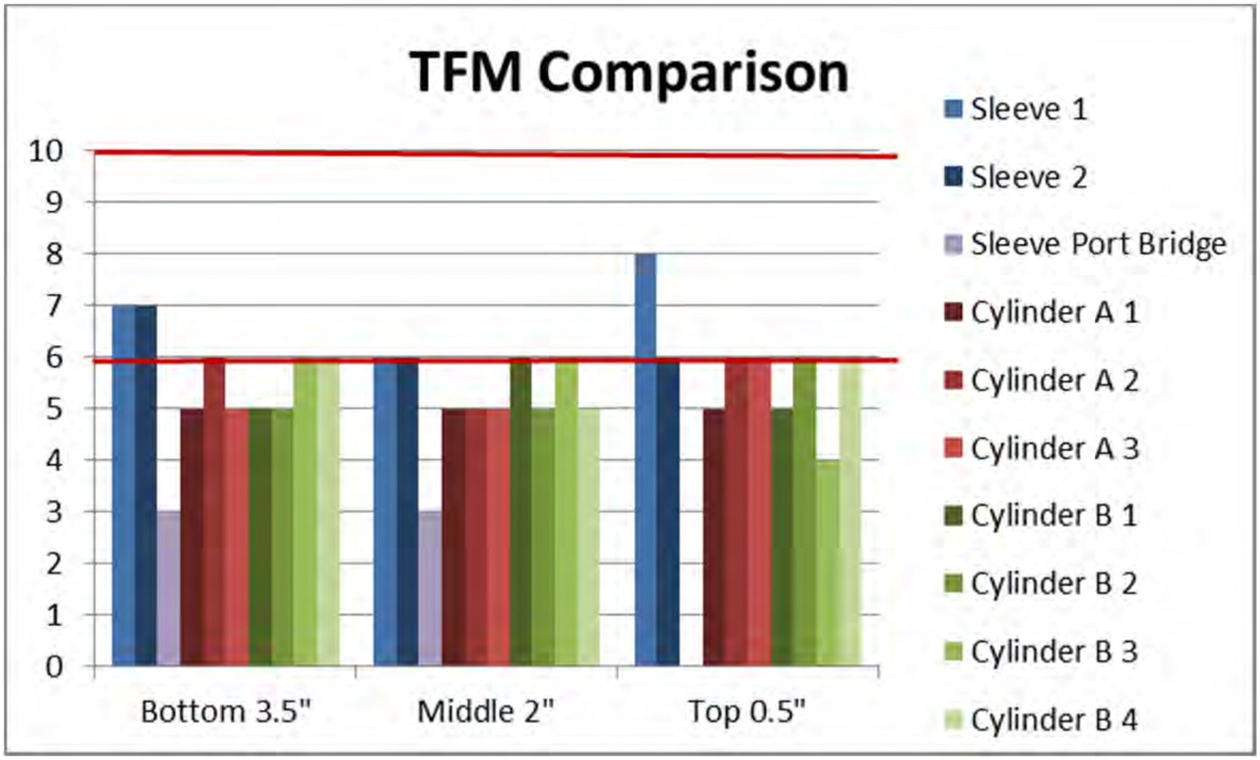


Figure 13: Comparison of TFM between the three blocks

The amount of Torn and Folded Material is very similar between the sleeve and the Hawk engine block. Both have consistent, deep, and unbroken hone-lines. These qualities are most important for the function of the Engine. The Hawk Engine Block has slightly rougher edges along the length of the Hone line, which accounts for the slight difference is Hone line ranking. Another aspect that should be noted is that in the Two Cycle Sleeve the bridges next to the ports have a rough ground finish with much lower quality Surface Finish. The Hawk Engine Block was not found to have this low quality area.

The CKE recommended specification (Table 2.1 pg. 4) for cross hatch angle is 25-35 degrees (Red Bars). In general a lower cross hatch angle may increase the possibility of top ring scuffing.

All but one location have values that differ from current CKE recommendations

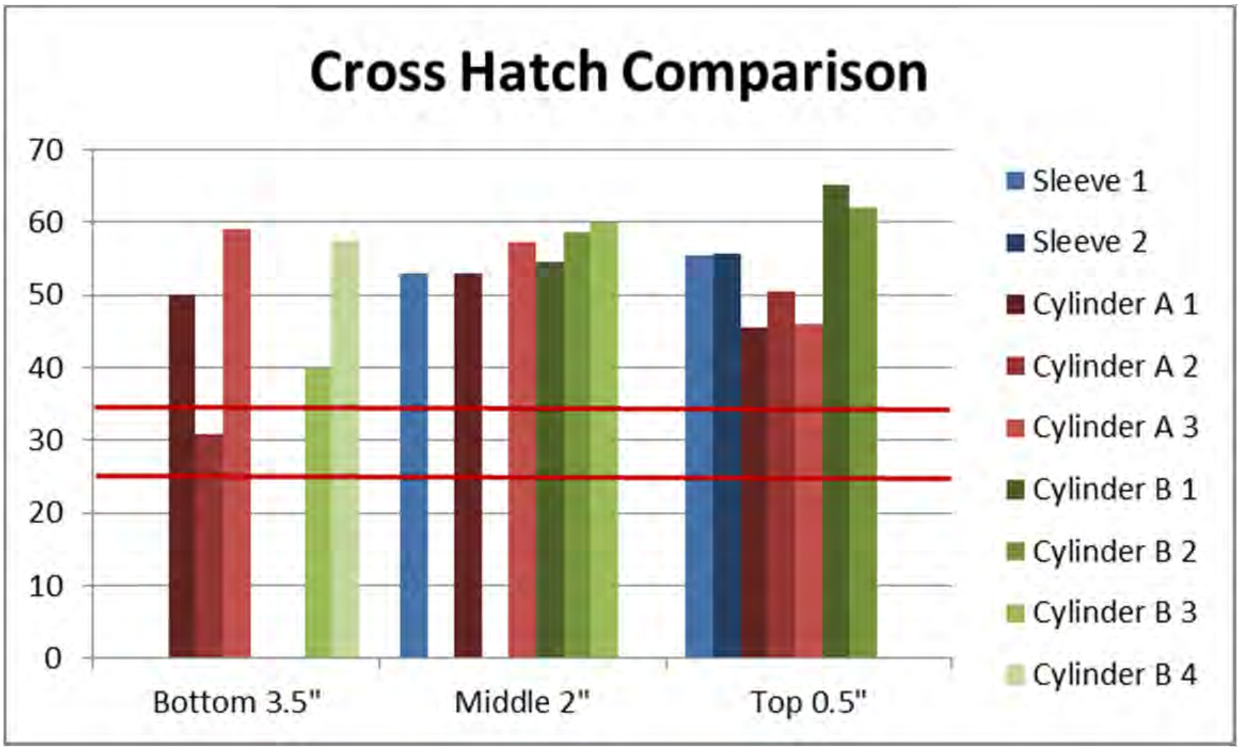


Figure 14: Comparison of X-Hatch between the three blocks

The Cross Hatch angle was similar in both the sleeve and the engine block. Both the Sleeve and the engine block have cases where there are unidirectional hone-lines.

Figures 15, 16, & 17 show typical traces from the Two Cycle Sleeve and Hawk Engine Block.

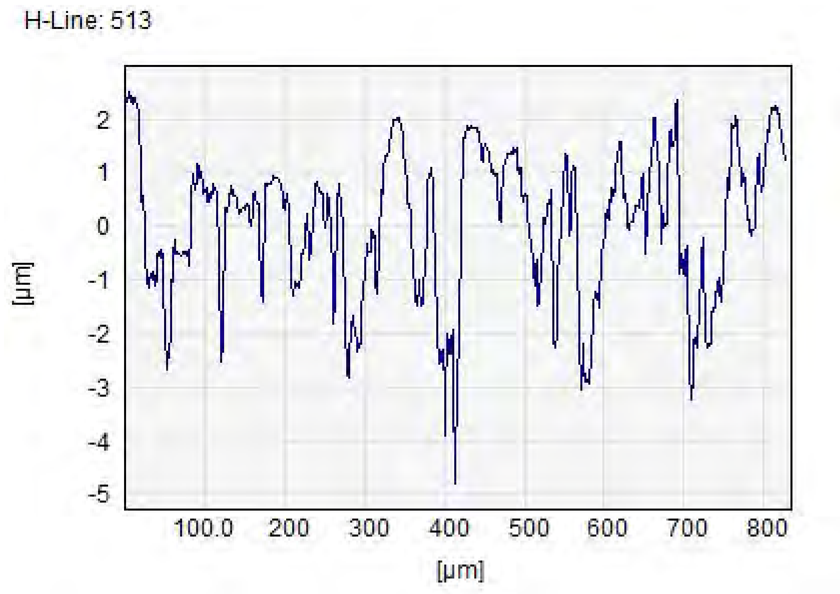


Figure 15: Customer XXX Two Cycle Sleeve Surface Roughness Trace Example from Appendix 1

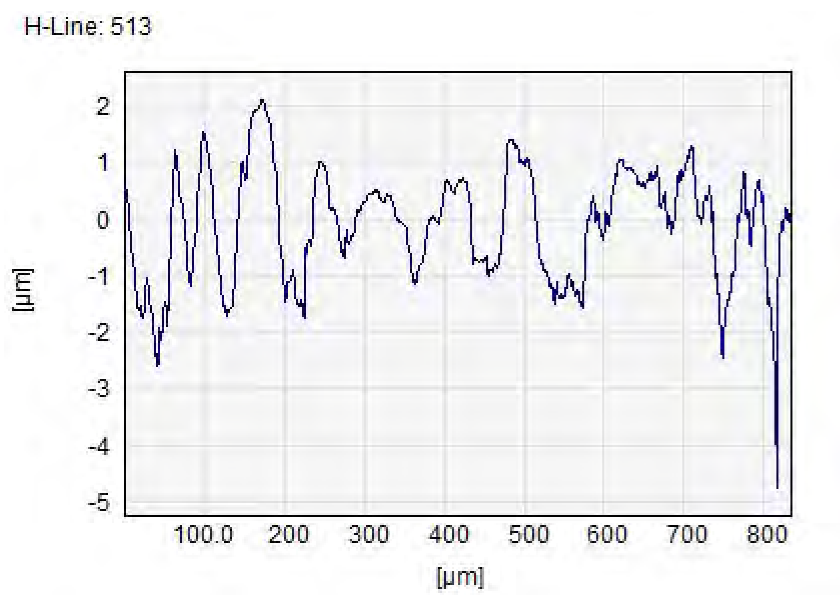


Figure 16: Customer XXX Hawk Engine Block Cylinder A Surface Roughness Trace Example from Appendix 1

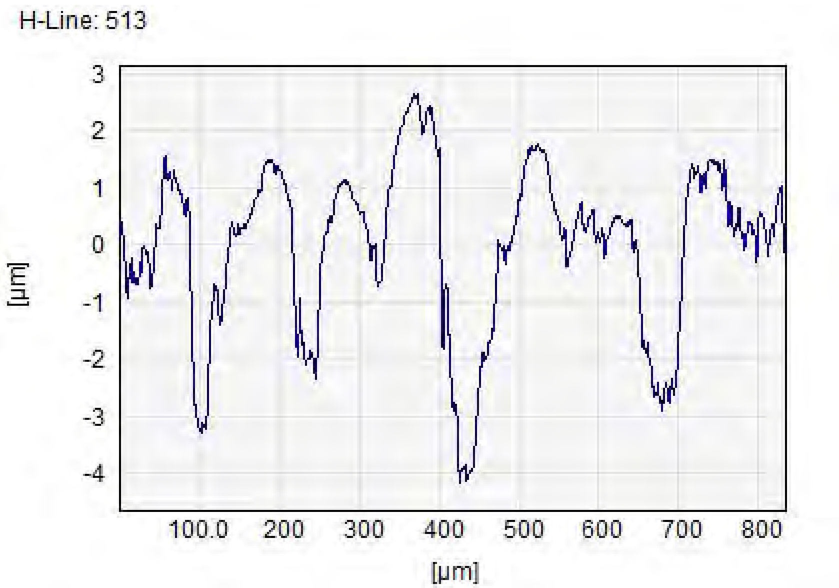


Figure 17: XXX Hawk Engine Block Cylinder B Surface Roughness Trace Example from Appendix 1

Conclusions:

Using the CKE SEE-3D system, it was found that the Surface Finish of the Customer XXX Two-Cycle Sleeve and those of the Hawk Engine Block Cylinders were very similar. However there are a few differences to be noted between the surfaces.

1. The Surface Finish Values were found to be better in the Hawk Engine block for 3D surface finish parameters S10z, Spk, and Sk

2. The Torn and Folded material was in general found to be very similar between the block and the sleeve. Two main differences were noted.
   2.1. The edges along the length of the Hone Lines in the Engine Block were slightly rougher than in the Sleeve
   2.2. The Sleeve was found to have very poor quality areas in the port bridge areas of the bore. This low quality area was not found in the Engine Block.