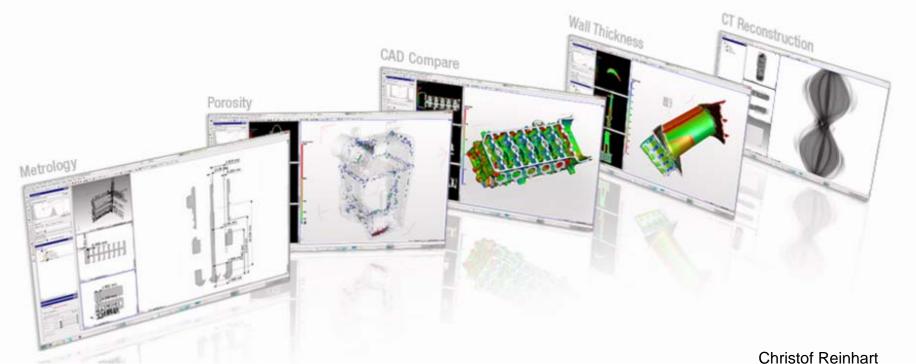


Conference in "Application of CT Scanning in Industry" at Danish Technological Institute, 31. May 2011

Industrial CT & Precision



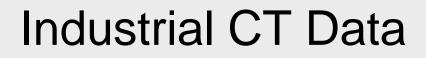
Volume Graphics GmbH, Heidelberg



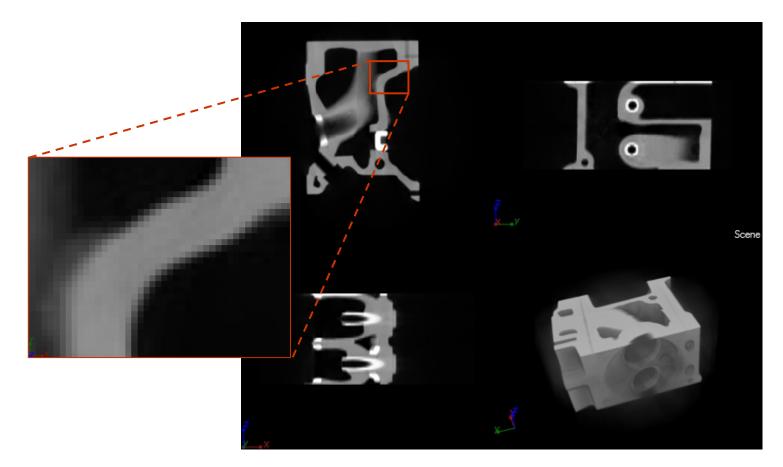
Industrial CT & Precision

- Overview:
 - Precision in CT-metrology.
 - Precision in defect analysis.
 - Precision in segmentation.
 - Bringing it together.



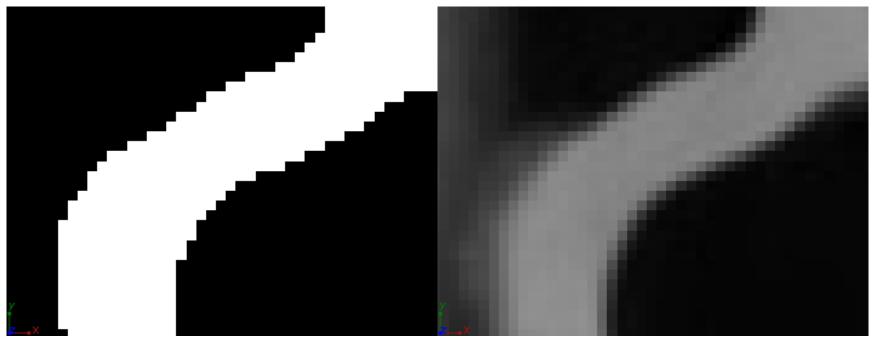


• All precision comes with the image data!





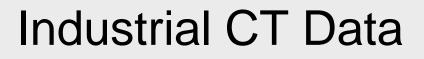
• Luckily CT data contains more information than just the "voxel". We get the grey values too.



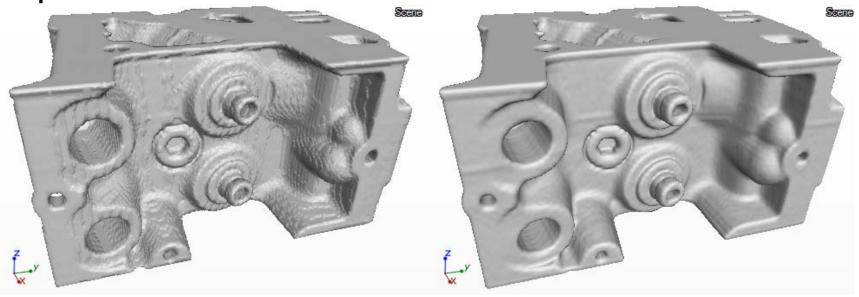
Voxels

Grey Values





 We can take advantage of the grey value information to make images look better and more important to make data analysis more precise.

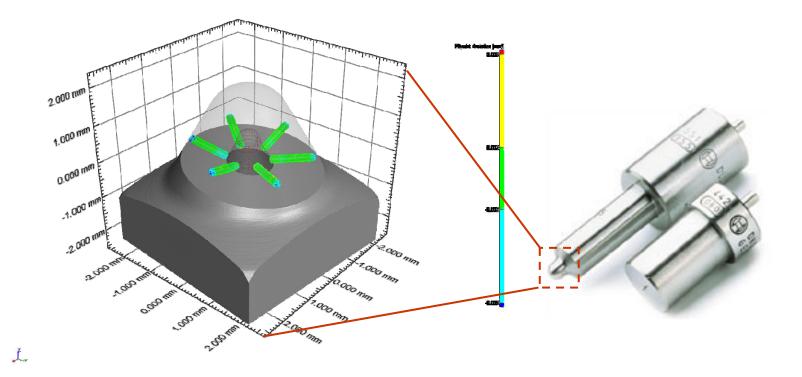


Voxels

Grey Values



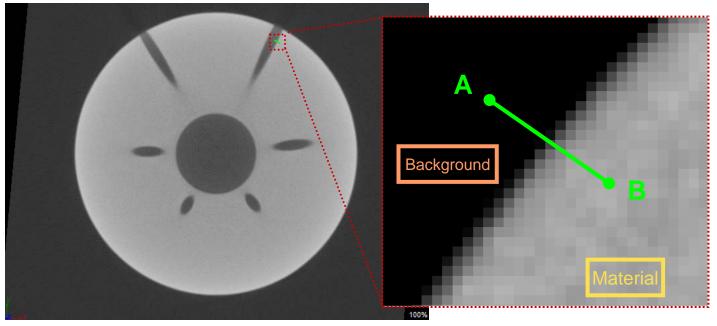
CT-Metrology





Surface Determination

- Precise surface determination is essential for various analysis tasks, especially for the use of CT in metrology.
- How do we measure on CT image data?
 - We have to localize the "edges" in the images = the object's surface in the images.



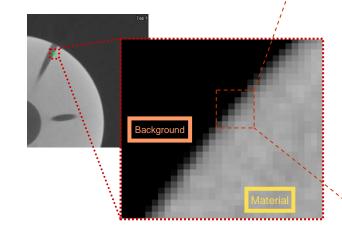


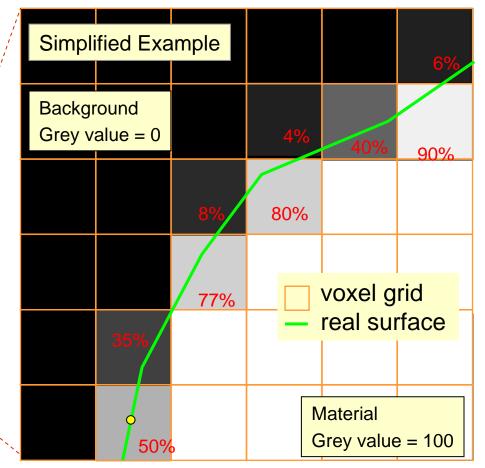
Surface Determination

• Why does the "surface look so blurred"?

Because of the **Partial Volume Effect**.

Voxels overlapping partially background and material receive an intermediate grey value according to the amount of material overlap.

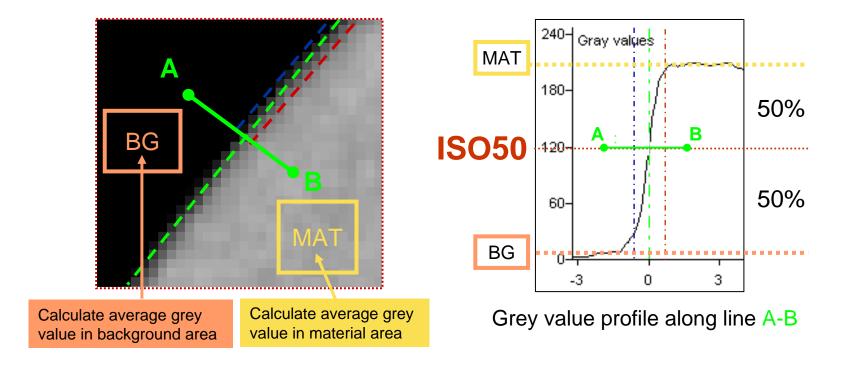






Surface Determination

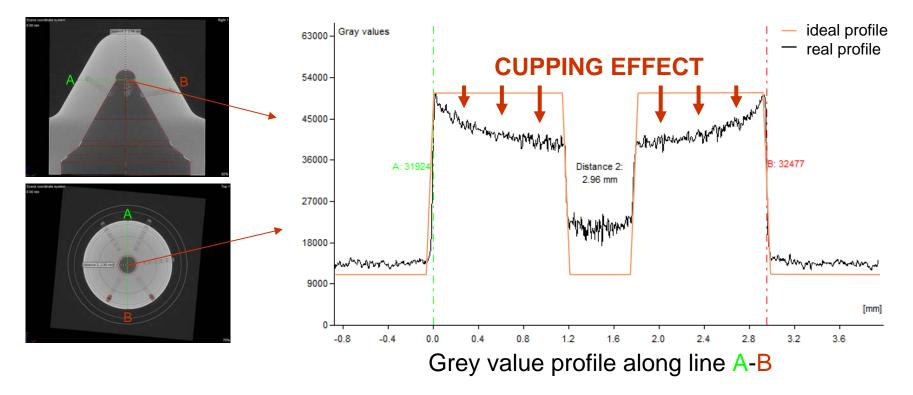
- In theory: The object's exact surface is described by a simple grey value threshold → ISO50 threshold.
 - ISO50=(average material grey value + average background grey value)/2







- Real data unfortunately contains artifacts
- Beam hardening / Cupping: Nozzle material grey value become imaged darker radial to the inside.

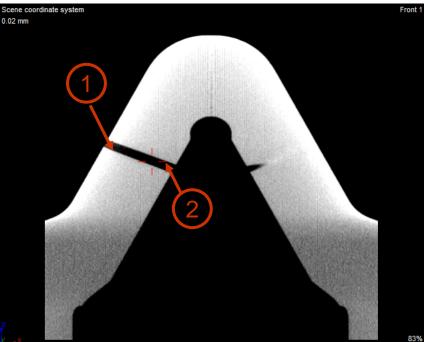






- A ISO50 threshold applied globally will typically cause geometry errors on "real data" since the local surface threshold at position 1 differs from the one at position 2 e.g. due to beam hardening artifacts.
- Fuel nozzle example: locally measured ISO50 threshold at:

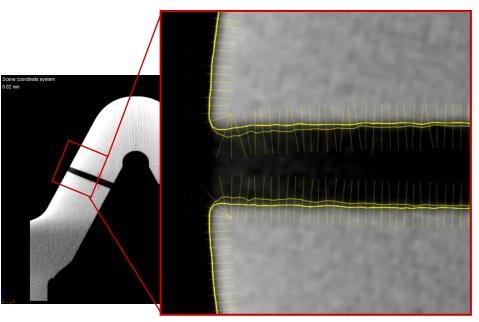
 1 = 38900
 2 = 32700





Precise Surface Determination

- Our surface determination uses a local adaptive edge detection algorithm to minimize measurement uncertainty.
- The upcoming 2.2 release uses higher computation accuracy to better support higher dynamic range CT data.
- All geometry related tools in our software take full advantage of this feature to reduce measurement uncertainty.



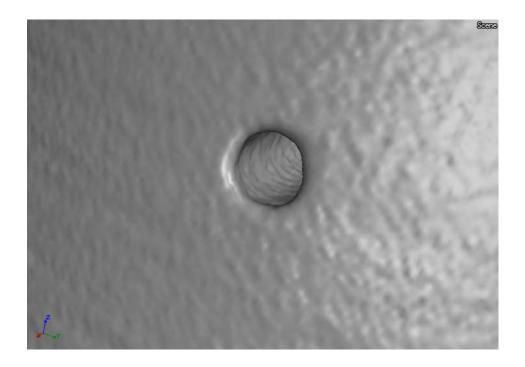
Thin yellow line = ISO50 surface

Thick yellow line = adaptive surface.



Precise Surface Determination

- What difference precise surface determination makes?
 - Visually: Injector borehole with and without local adaptive surface determination.





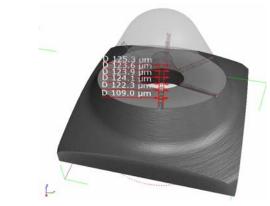
- What difference precise surface determination makes?
 - In numbers: Diesel fuel injector scanned on optotactile measurement system (today's established test method).
 - Diesel fuel injector scanned on a CT system with:
 - 225 keV micro-focus x-ray tube
 - 2048x2048 flat panel detector
 - Pre-adjusted scanner geometry
 - Post-scan scaling error correction (Scaling error as low as 1.00075)
 - Using ISO50 and adaptive surface determination.
 - Comparison of the results.

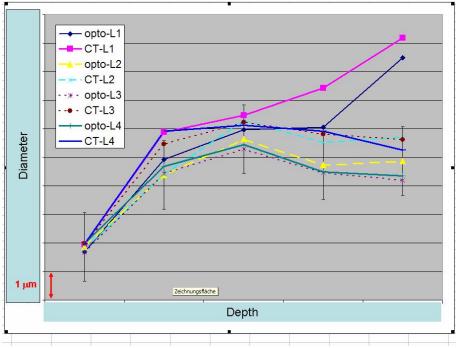


Injector Scan Results

- Measure 6 fuel injector nozzle boreholes diameters in 5 positions.
 - Scan/Voxel resolution
 8 μm
 - CT measurement with local adaptive surface compared to standard opto-tactile measurement < 1µm

The graph shows the comparison of 4 classical **opto-tactile** drill hole diameter measurements with **CT** based measurements.



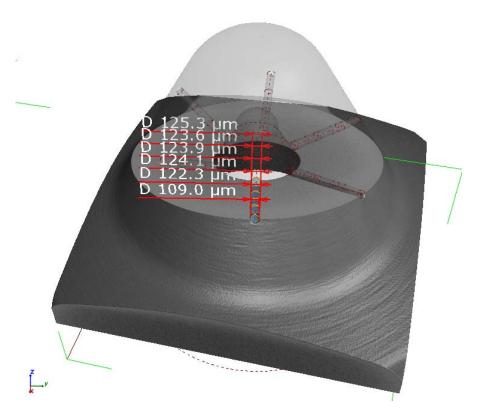




Injector Scan Results

- Final result: CT is able to reproduce classical measurements.
 - Measurement uncertainty
 >= 5 μm by using a global ISO50 surface threshold.
 - Measurement uncertainty
 <= 1 μm by using local adaptive surface determination.

2003 Forµprod & PhD Thesis, Dr. Heinz Steinbeiß, UTG Munich

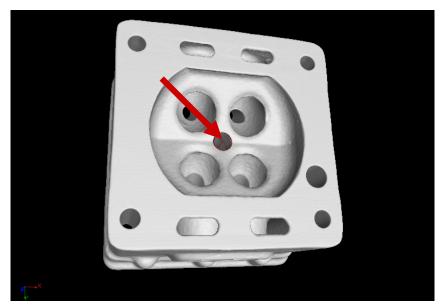




- Local adaptive surface determination is today's accepted standard and used by many vendors.
- As a simple rule of thumb we tell that: "you can reach about 1/10 of a voxel in measurement uncertainty with good image quality CT data".
- But, is this the final limit and what is the "true" nominal value?



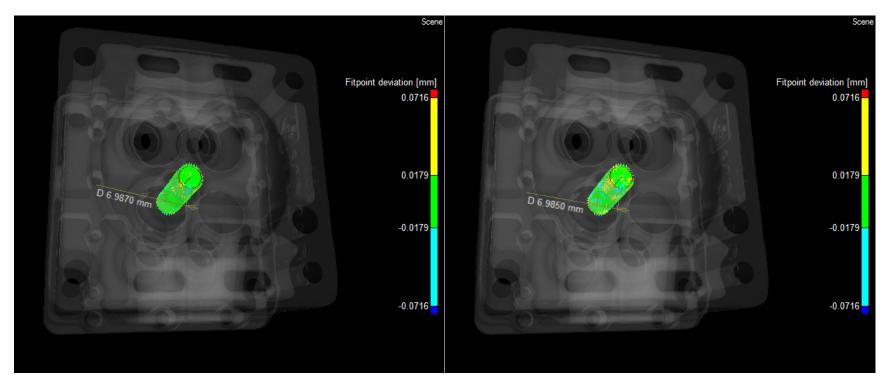
- We have to rely on today's accepted standards as "the truth" and compare CT measurements with them.
- Measurement task: Measure the diameter of a borehole in an aluminum cylinder head calibrated by a DKD laboratory.
- Measured "CT-style", probing the complete cylinder surface with e.g. 1000 points.





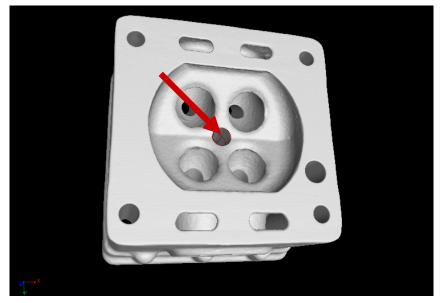
- Nominal by DKD Z14-DM = **6.9966 +/- 0.001 mm**
- Scan 1 (0.140mm resol.) Z14-DM = 6.9870 mm
- Scan 2 (0.220mm resol.) Z14-DM = 6.9850 mm

Z14-DM = 6.9900 +7-0.001 mmZ14-DM = 6.9870 mm Z14-DM = 6.9850 mm





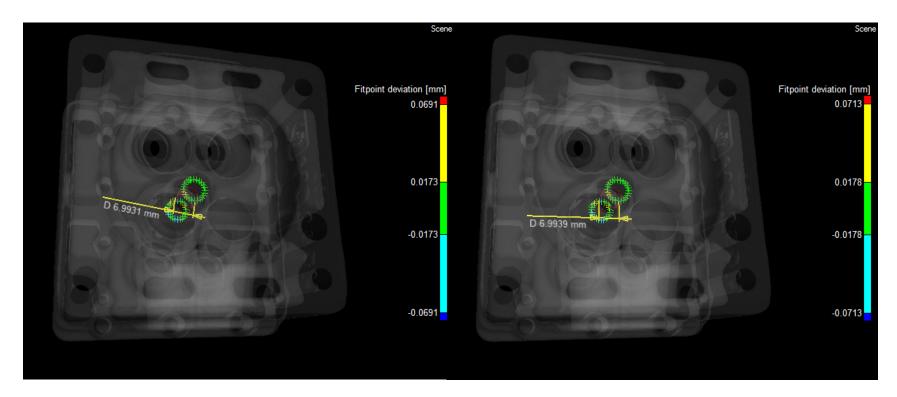
 Measured "CM-style", create a cylinder by probing two circles with 24 points in y=18 mm and 43 mm, following the DKD measurement strategy.





- Nominal by DKD Z14-DM = **6.9966 +/- 0.001 mm**
- Scan 1 (0.140mm resol.) Z14-DM = 6.9931 mm
- Scan 2 (0.220mm resol.) Z14-DM = 6.9939 mm

4-DM = **6.9966 +/- 0.001 mm** Z14-DM = 6.9931 mm Z14-DM = 6.9939 mm





- This example shows two important things:
 - 1. The measurement strategy is one of the most important aspects when we continue seeking for even lower measurement uncertainty in CT-metrology.
 - 2. A 1/10 of a voxel is not the limit once we get even better image quality.





Defect/Inclusion Analysis

 So far we use a voxel based – kind of "binary" – yes/no decision if a voxel belongs to a defect.

16 504

8.467

8,263

6.919

6.875

6.831

6.633

6.038

8.016

5.553

5.773 262

5.509 250

14.51

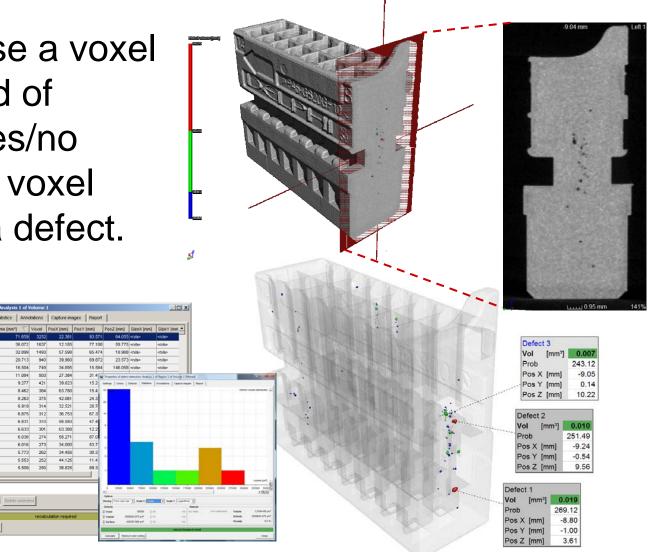
2.63

1.45

Copture from: Top 1

Delete selection

Calculate Remove color coding





Defect/Inclusion Analysis

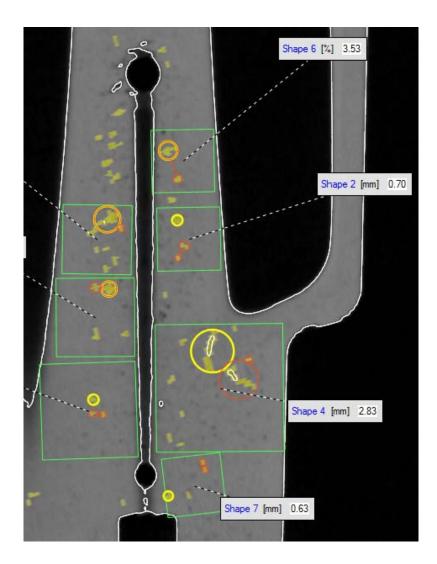
- However in our 3D defect analysis tool we already used a local adaptive threshold to localize defects within environments with different levels of contrast.
- Statistically across large samples of defects the e.g. total volume or percentage of porosity was calculated quite accurate. Some defects volumes calculated in voxels are too big while some others are too small.

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2 Avalysis 1 5.50 36.07 1637 12.168 77.100 3 Avalysis 5 37.41 22.089 1402 67.590 66.474 4 Analysis 1 1.11 22.089 1402 67.990 66.474 5 Analysis 1 1.94 10.504 749 39.800 60.872 6 Analysis 1 1.81 11.086 500 27.394 39.602 15.594 6 Analysis 1 2.00 9.207 421 39.62 15.247 8 Analysis 1 7.21 6.462 39.63 53.20 15.423 9 Analysis 1 7.24 8.423 37.5 42.081 24.375 9 Analysis 1 5.24 8.263 37.5 42.081 24.370 9 Analysis 1 5.54 6.545 51.42.070 22.27 20.700	9 90.775 ender ender of data finishes headed of fileges (1 of heads) (1 of heads) (1 of heads) 1 of heads 1 of heads) (1 of heads) (1 of heads) (1 of heads) (1 of heads) 1 of heads) 1 of heads) (1 of h
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6 Analysis 1 1.61 11.064 900 27.384 31.461 7 Analysis 1 2.03 9.277 421 99.802 15.247 8 Analysis 1 7.21 0.462 364 63.700 15.423 9 Analysis 1 7.24 0.462 375 42.06 63.700 15.423 9 Analysis 1 5.24 6.828 375 42.064 24.375 10 Analysis 1 5.24 6.949 314 2.5251 20.870	3 13.857 •1/40~ •n 7 1463.51 •n/40~ •n 3 113.473 •n/40~ •n
7 Analysis 1 2.03 9.277 421 39.023 152.47 8 Analysis 1 7.21 8.462 364 65.780 155.47 9 Analysis 1 1.54 8.263 37.5 42.061 24.376 10 Analysis 1 5.54 6.549 374 32.52 20.700	7 146.351 «n/a» «n/ 3 113.473 «n/a» «n »
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	0 10.203 «n/a» «n
11 Analysis 1 3.71 6.875 312 36.753 67.354	4 21.073 m/s> m -
12 Anelysis 1 10.82 6.831 310 58.593 47.461	1 17.819 m/s> m :-
13 Anelysis 1 3.32 6.633 301 63.388 12.210	0 107.053 «n/a» «n
14 Analysis 1 1.99 6.038 274 58.271 87.076	5 64.295 m/ax m +
15 Anelysis 1 1.26 6.016 273 34.000 53.772	2 146.923 m/s> m
16 Analysis 1 14.51 5.773 262 34.456 30.376	
17 Analysis 1 2.63 5.553 252 44.125 11.472	
18 Analysis 1 1.45 5.509 250 38.825 89.341	1 121 276 en/s> en
4	There will be reader when the
	Types Hill(1) is box 100



- P201 / VW 50097
 2D defect analysis
 now comes with subvoxel precision.
- P201 uses features

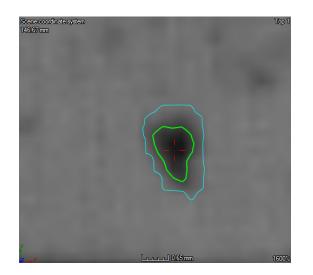
 of individual defects
 like the defect
 circumscribing
 circle's diameter, etc.





• The comparison between voxel and sub-voxel precise defect analysis shows significant differences and is essential for the analysis on the scale of individual

defects.



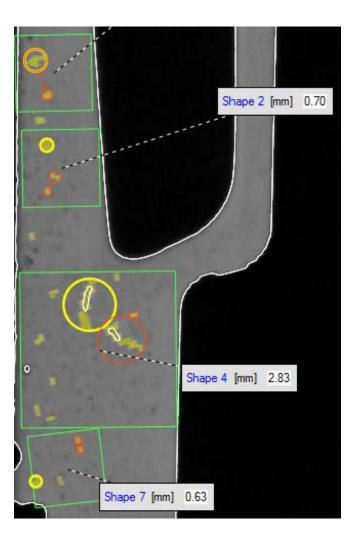
Cyan color line = voxel based defect contour.

Green color line = Sub-voxel defect contour.

 This is essential if you want to compare "high resolution" micrograph section results with "low resolution" CT analysis results.



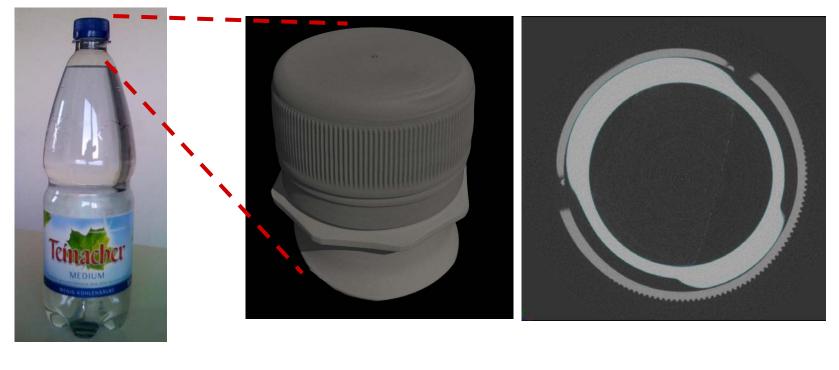
- Here sub-voxel precision is essential and will better support/allow the comparison between classical polished micrograph section based and CT based porosity analysis.
- Besides the wish to follow established standards this will build up more trust in CT based defect analysis.







• Measure water bottle cap contact surface area.



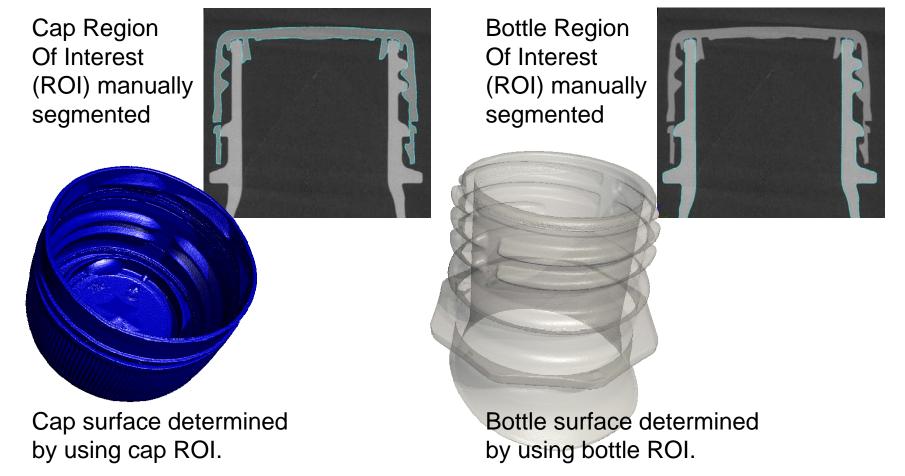
Photo

40 μm CT-scan

slice image not aligned



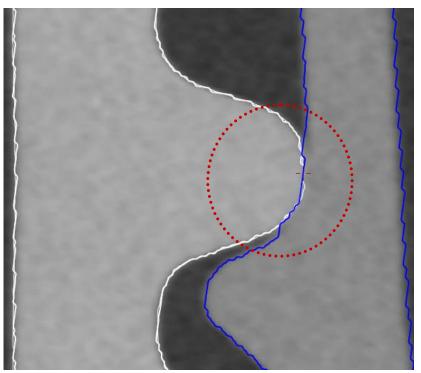
• Measure water bottle cap contact surface area.





• Measure water bottle cap contact surface area.



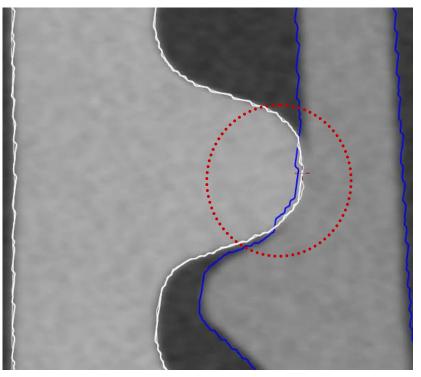


White outline: bottle surface. Blue outline: bottle cap ROI.



• Measure water bottle cap contact surface area.



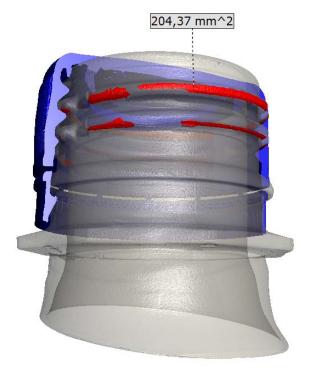


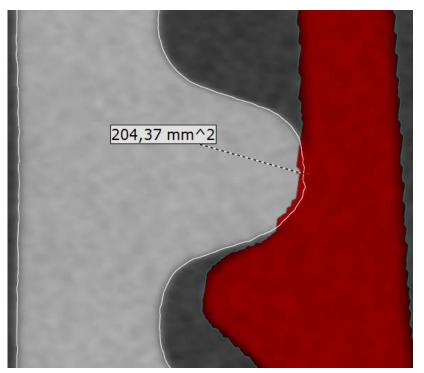
Expand bottle cap ROI by one voxel.

• The upcoming 2.2 release supports sub-voxel precise ROIs.



• Measure water bottle cap contact surface area.

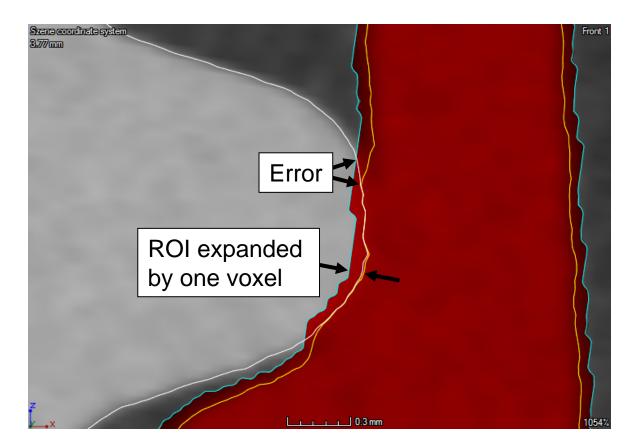




Measure amount of bottle surface area within red expanded bottle cap ROI.



- Contact surface area is measured to large.
- Sub-voxel precise segmentation will reduce this error.





Sub-Voxel Precise Segmentation + Local Adaptive Edge Detection + CAD Support

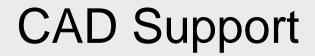




 VGStudio MAX 2.2 will offer CAD (STEP, IGES,...) assisted surface determination, subvoxel precise segmentation.





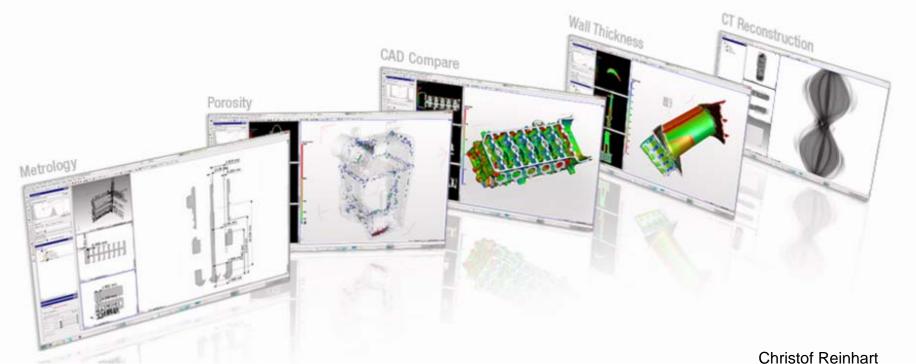






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Thank you for your attention!



Volume Graphics GmbH, Heidelberg