MSc Defence - Friday 28th, April 2017 Academic Year 2015/2016

Technological signature in precision injection compression moulding of polymer Fresnel lens

Department of Mechanical Engineering - Section of Manufacturing and Production Systems

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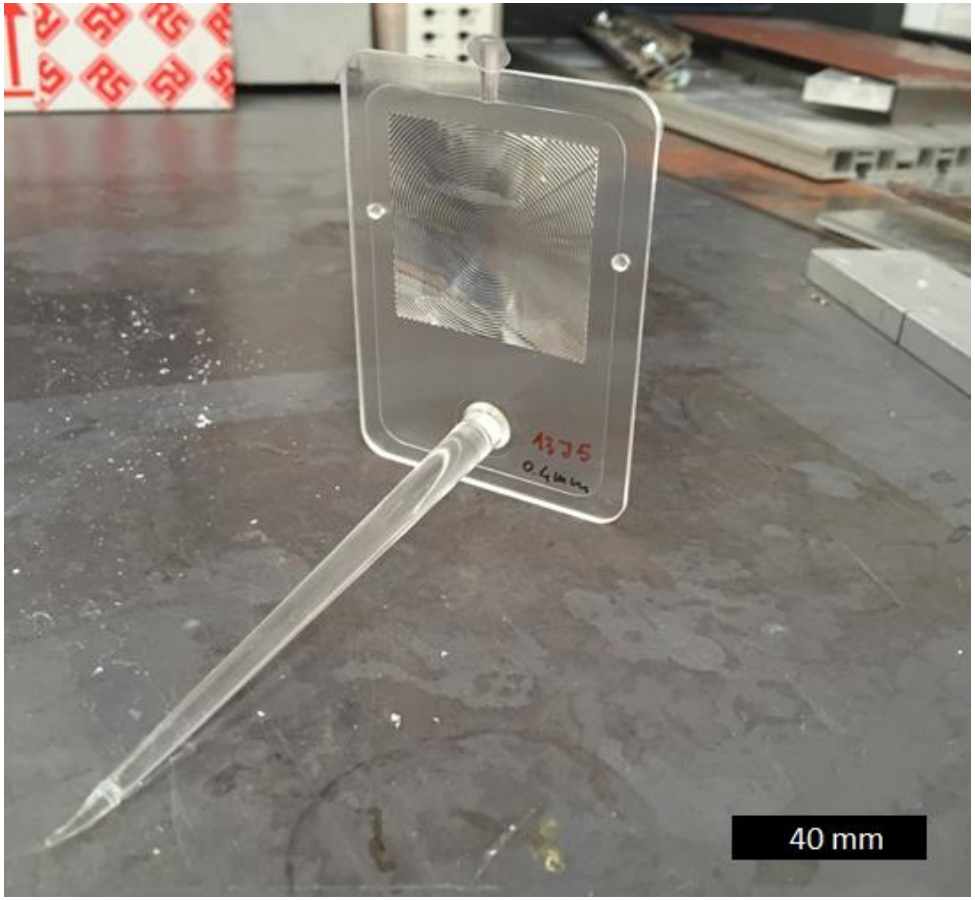
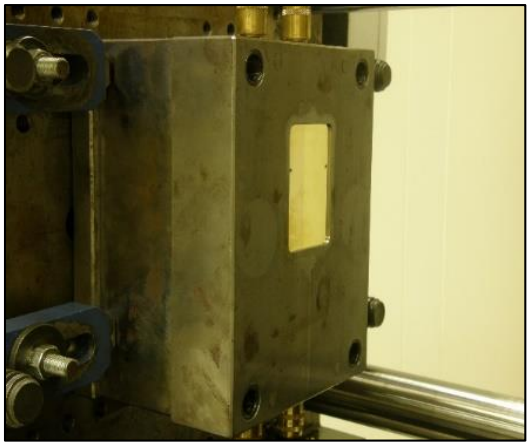
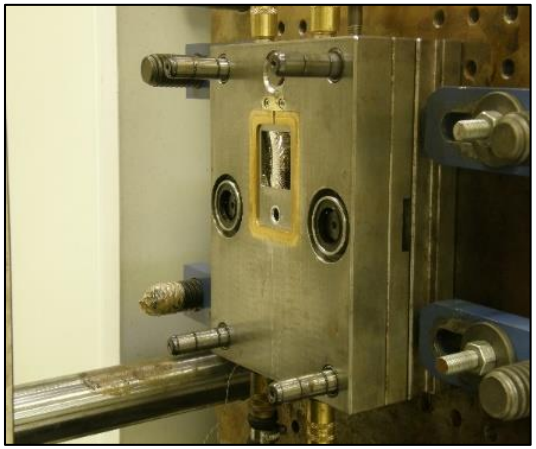
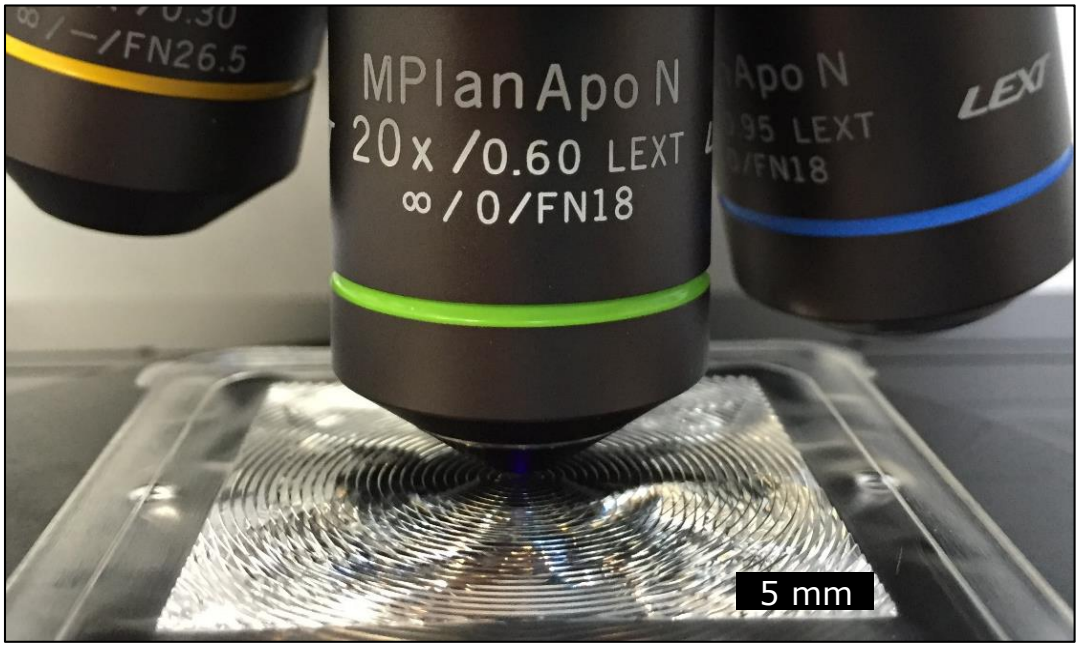
- Introduction
- State of the art
- Metrology
- DOE
- Results and conclusions



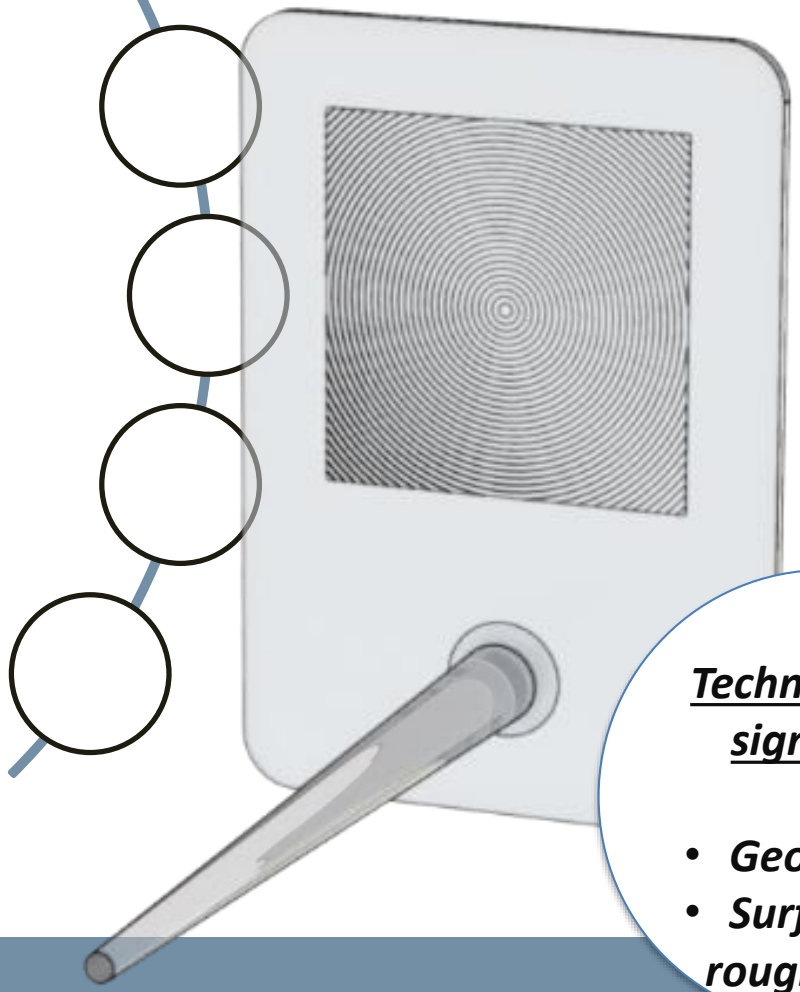
Introduction



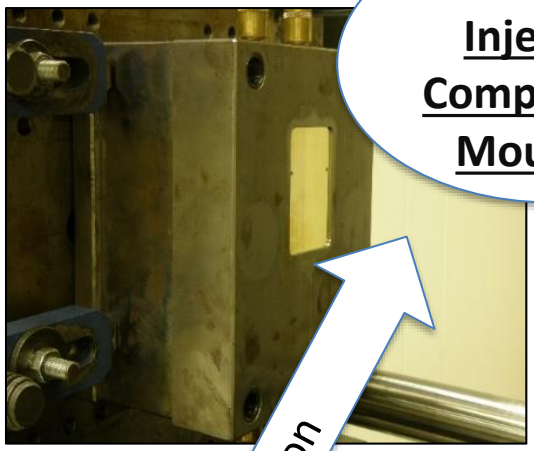


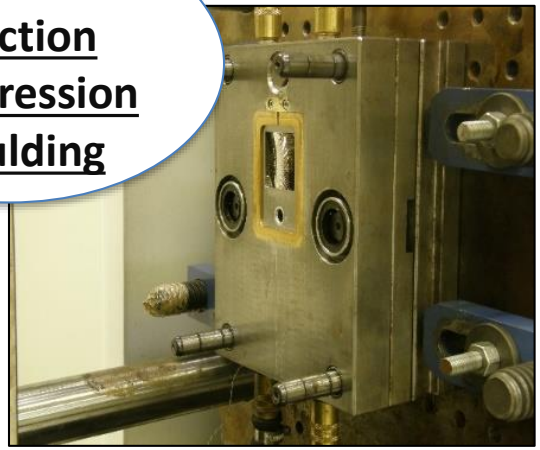


Introduction

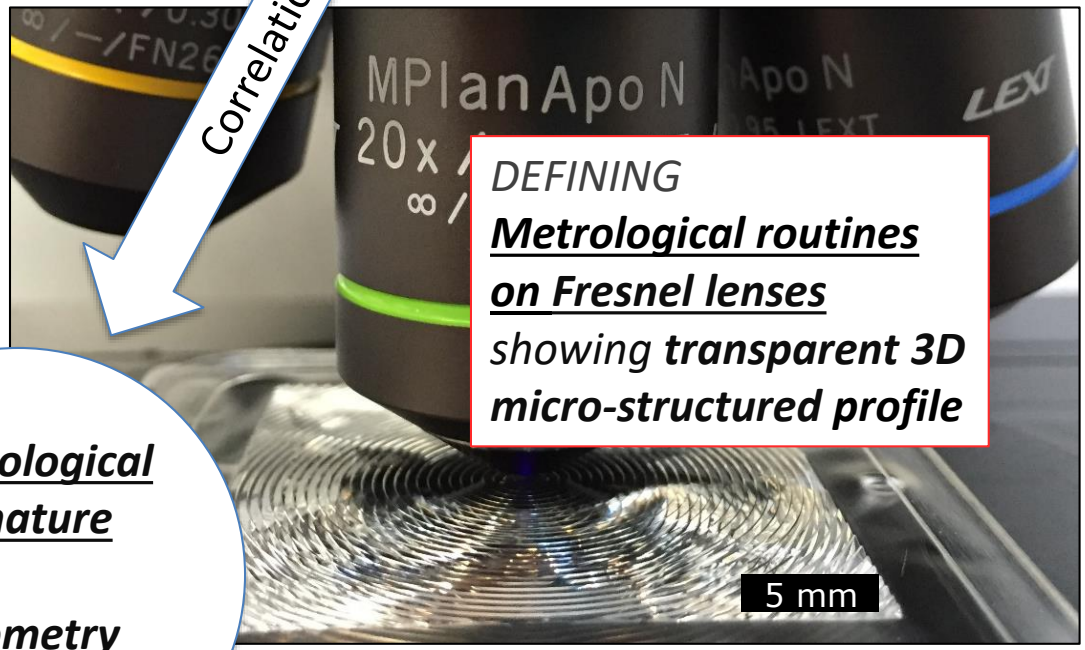


MASTERING
Injection Compression Moulding





Correlation



DEFINING
Metrological routines on Fresnel lenses
showing ***transparent 3D micro-structured profile***

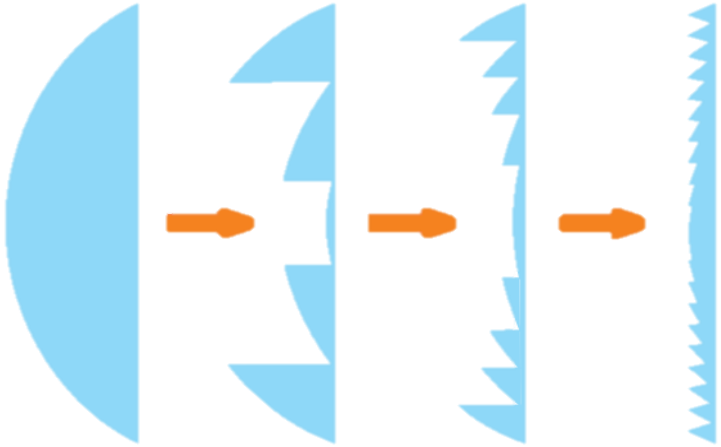
Technological signature

- ***Geometry***
- ***Surface roughness***

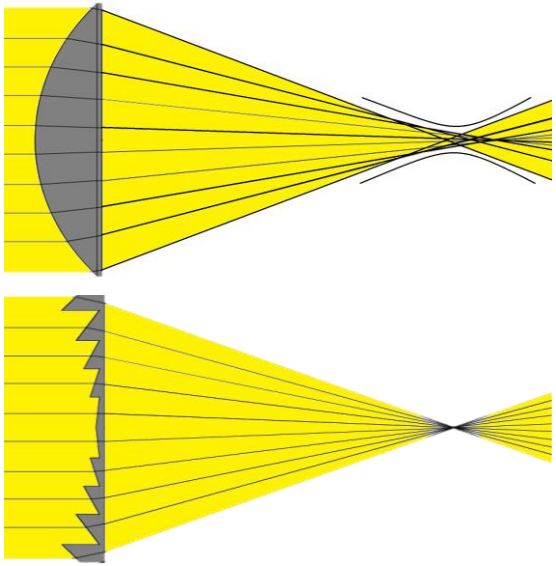
on Fresnel lenses:

Copyright from top left: Ferrari®, Kilauea's municipality, Areva®, Apple®, Zylight®

- ***Lighter and more compact design*** *(Davis et al. 2007)*

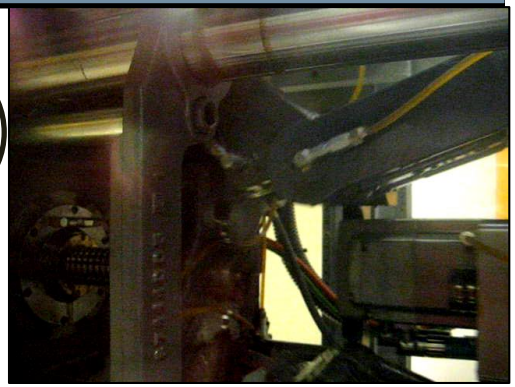


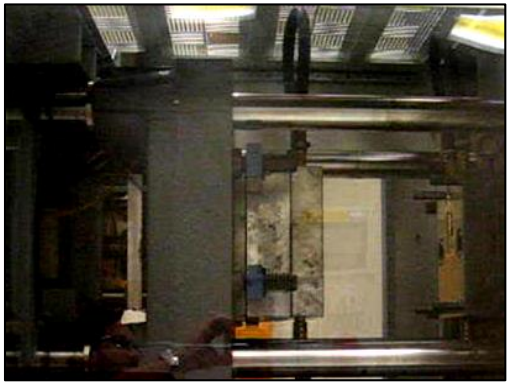
- ***Reduction of spherical aberration*** *(John 2013)*



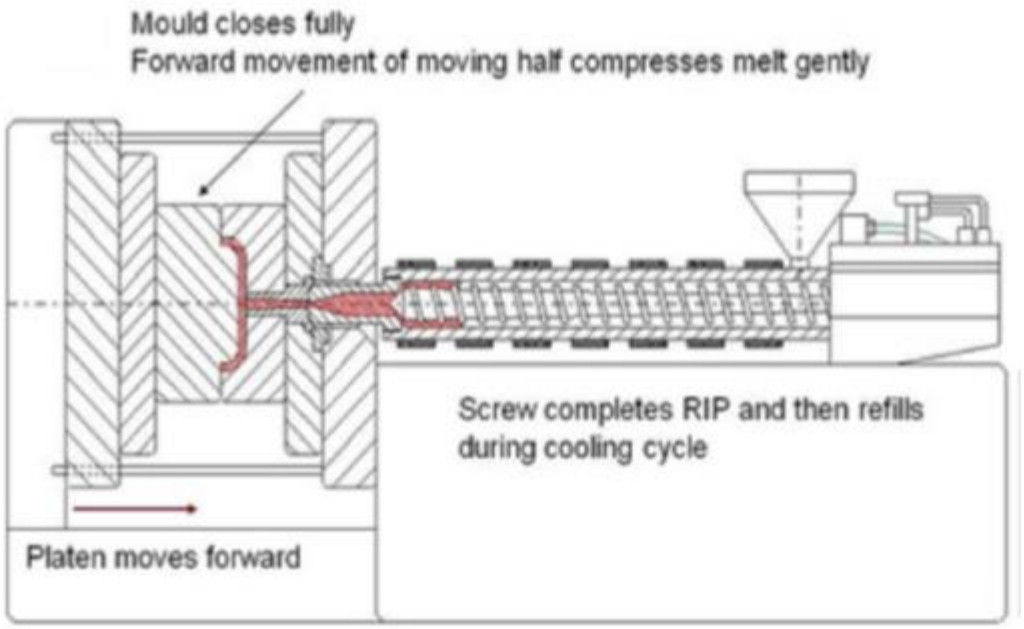
on Injection Compression Moulding:

State of the art





Compression Phase



www.plastemart.com

Advantages against Injection Moulding (Hansen et. al 2011):

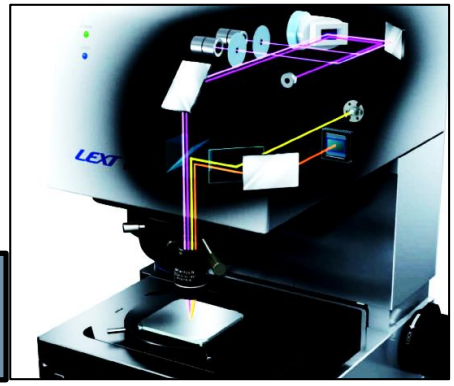
- ***Lower volumetric shrinkage***
- ***Improved mould capacity replication***
- ***Better transparency***

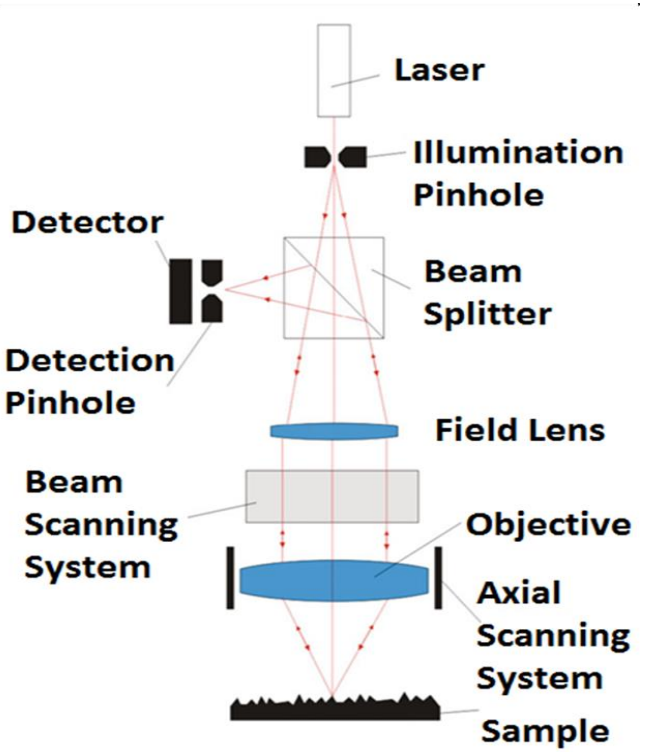
Additional process parameters:

- ***Compression gap***
- ***Compression starting point***

on Laser Scanning confocal Microscope:

State of the art

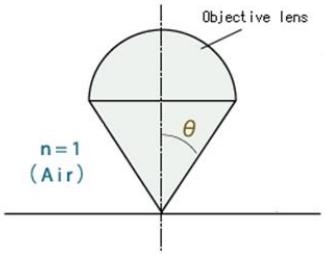


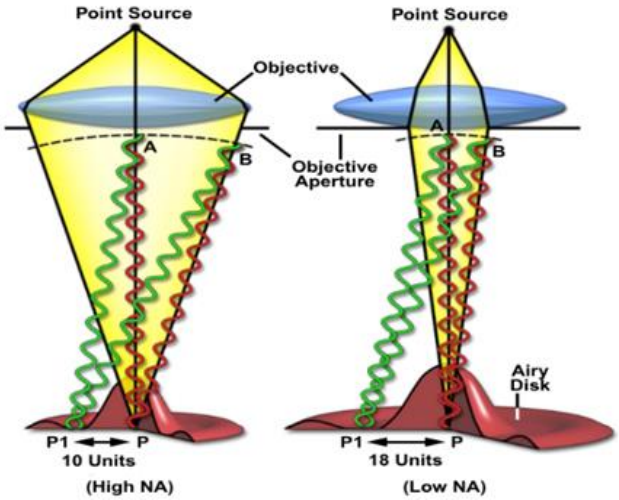


Microscope architecture (Leach 2014)

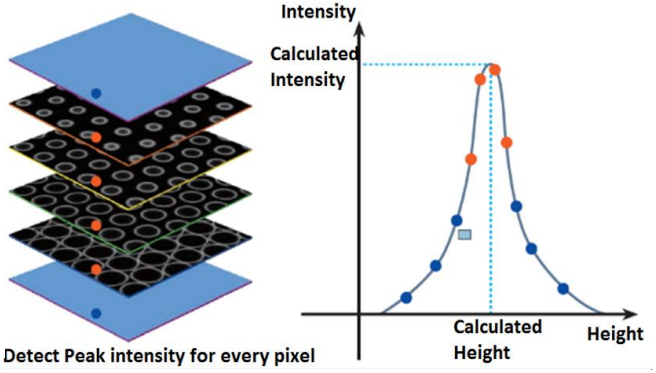
$$Rl = 0.73\,\frac{\lambda}{NA}$$

$$NA = n\,\sin\vartheta$$





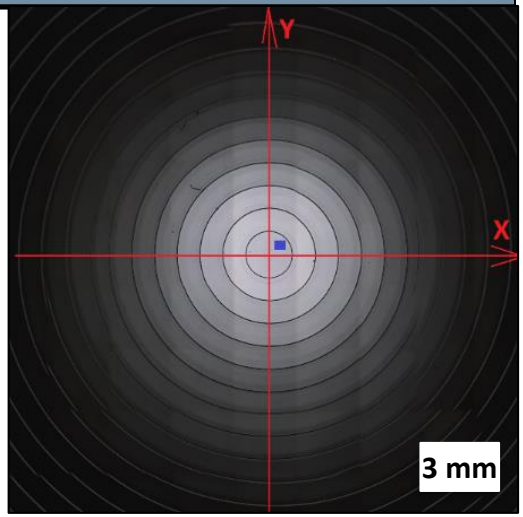
Numerical Aperture and Objective Selection (microscopyU.com)

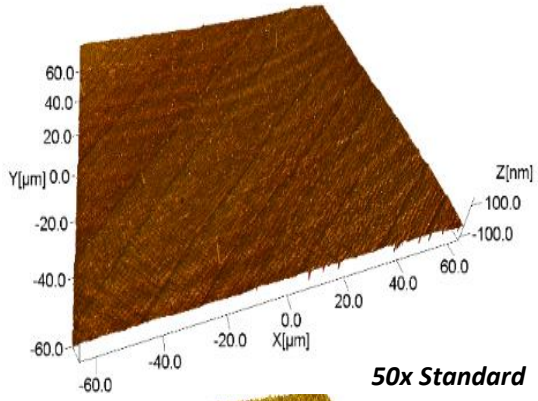


Physical principle of Olympus®lext

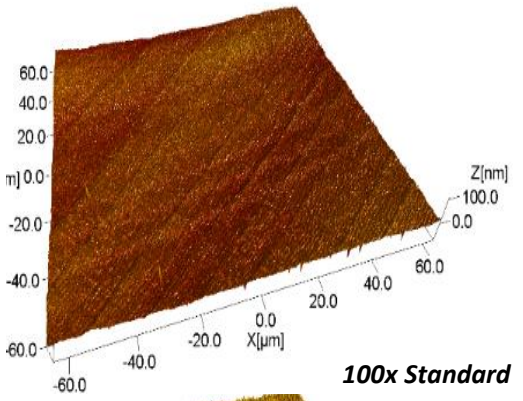
Roughness preliminary analysis:

Metrology

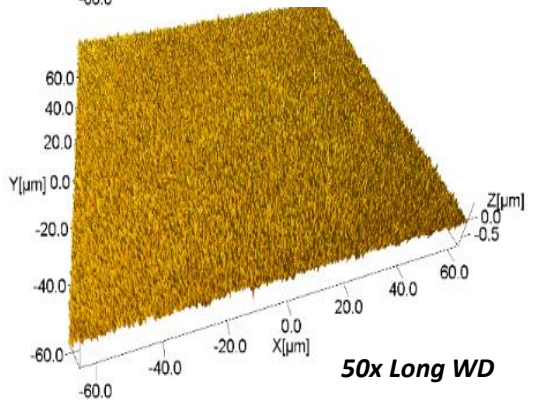




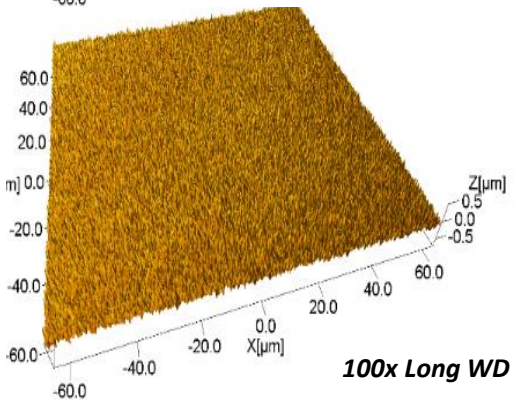
50x Standard



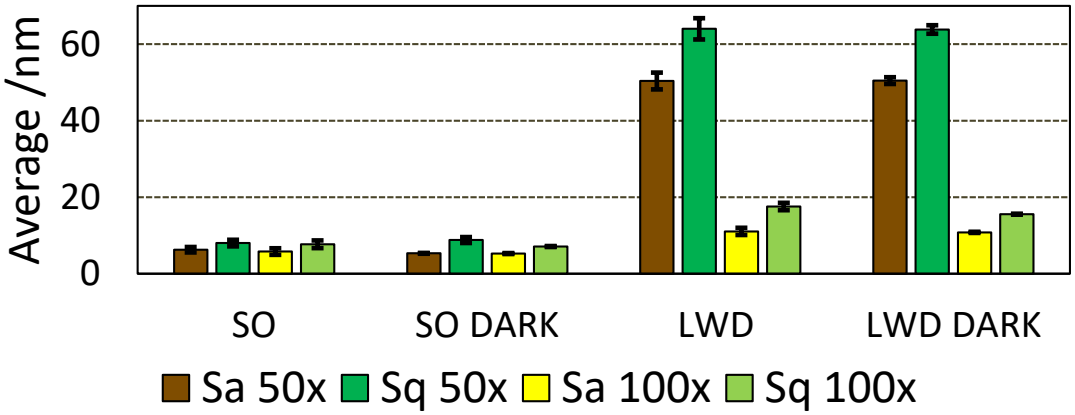
100x Standard



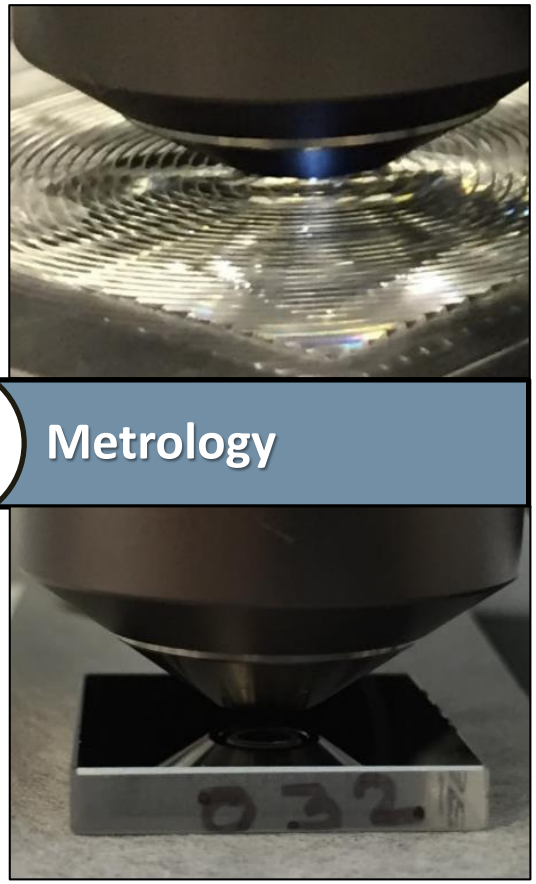
50x Long WD



100x Long WD

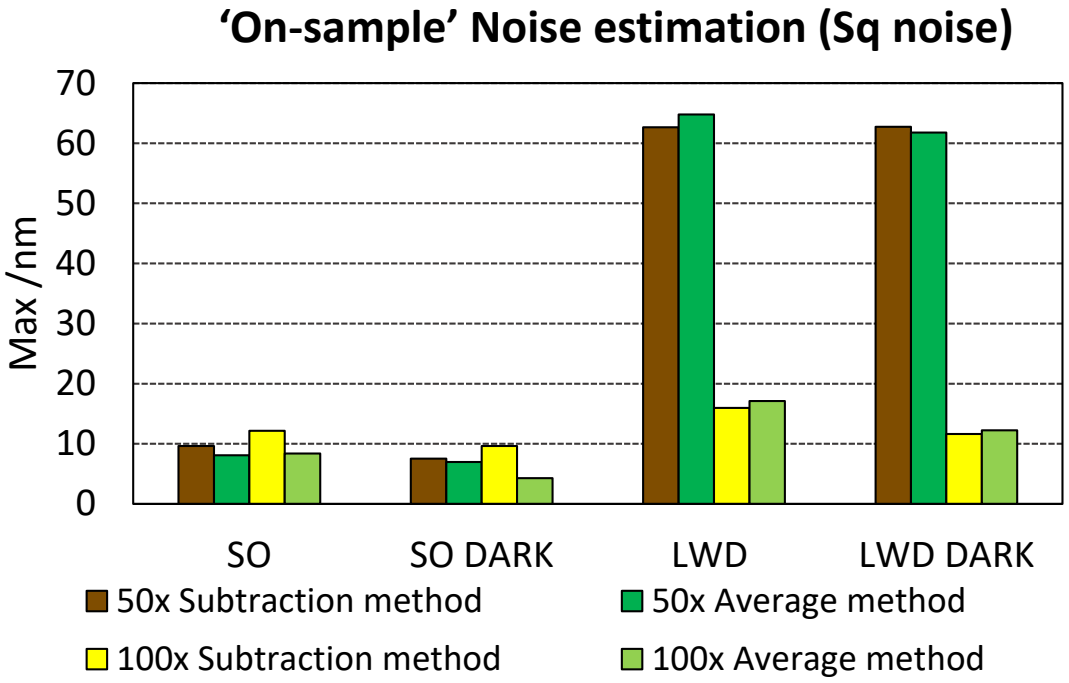


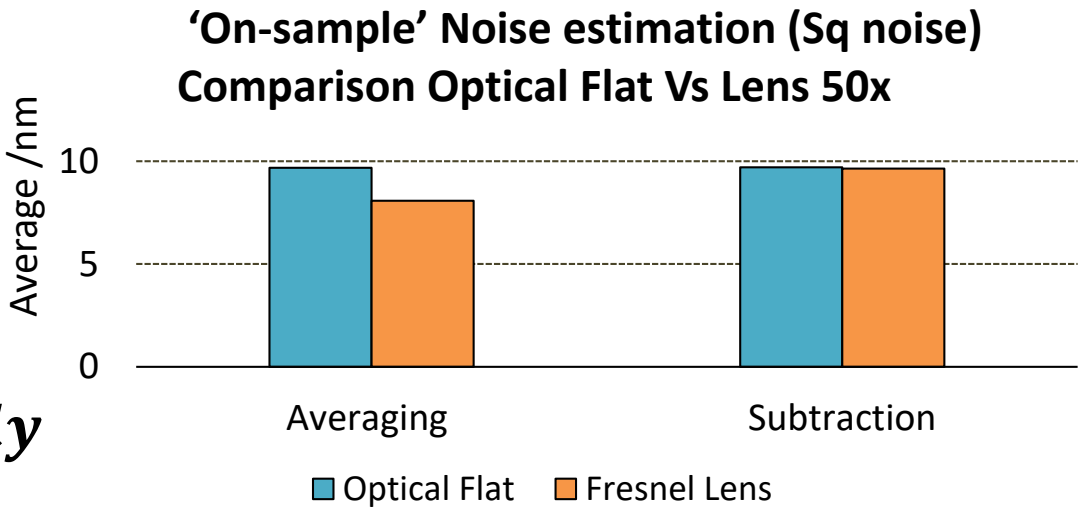
Noise estimation:



Metrology

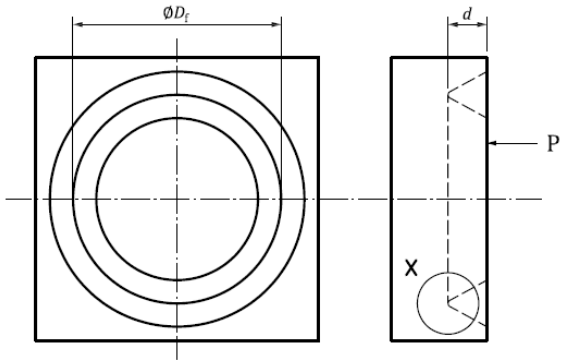
$$Sq = \frac{1}{A}\iint (z - z_0)^2 \, dxdy$$





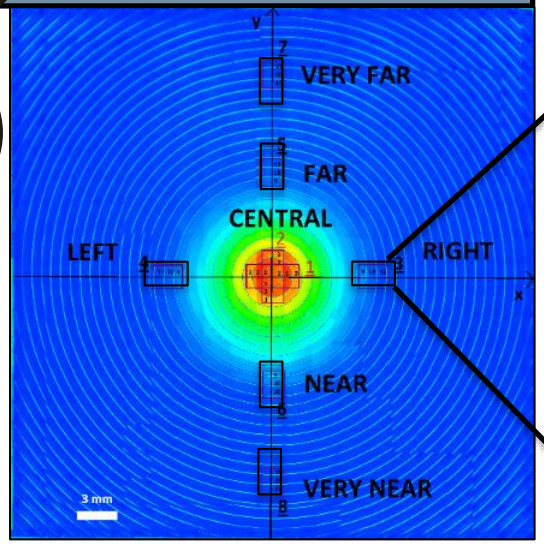
Dimensional length definitions:

Reference Standard – ISO 25178-70:2014

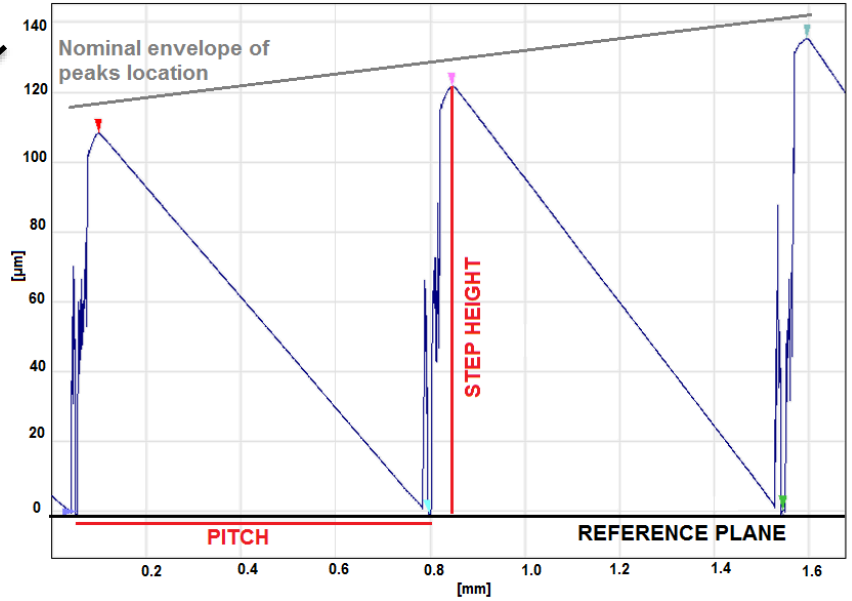


P reference plane
d depth of the groove

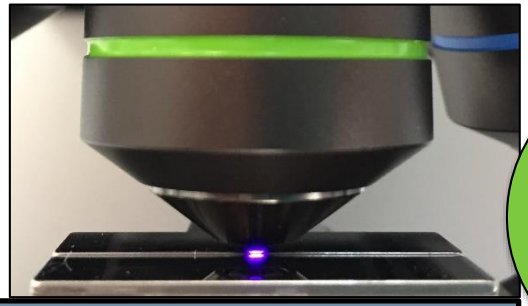
Metrology



Application of the standard to the sample profile



Dimensional length Uncertainty budgets:



Metrology

$$U = k\sqrt{u_b^2 + u_c^2 + u_p^2 + u_w^2}$$

Ub
20 replicates on optical flat

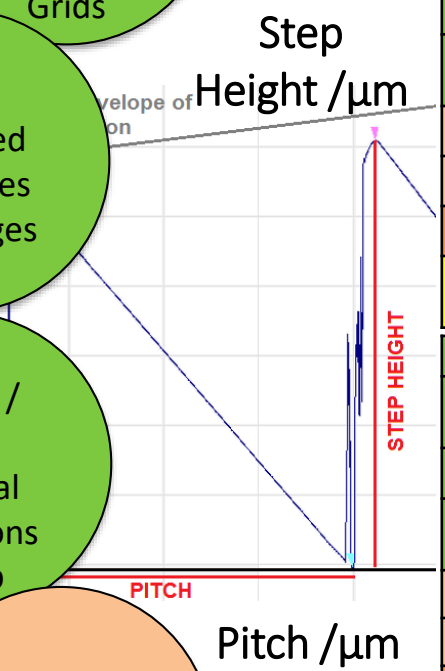
Uc
10 replicates on Gauge blocks / Grids

Up
10 repeated measures on Gauges / Grid

Uwp
Gauge / Grid thermal conditions in Lab

Uwp
10 process replica

Uwt
Sample thermal conditions in lab



Reference Standard
ISO 15530-3:2011

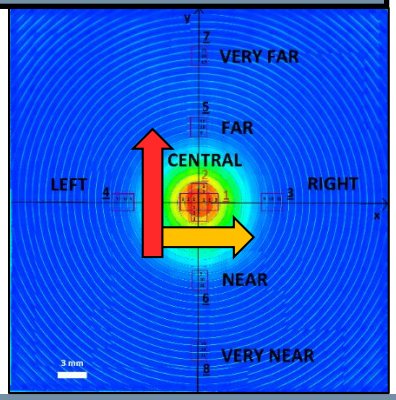
ub	0.0	*Background noise*
uc	0.1	*Calibration certificate*
up	0.6	***Procedure***
ub	0.0	*Uncertainty due to systematics*
u_{wp}	0.4	***Workpiece – process***
u_{wt}	0.0	*Workpiece – material*
u_w	0.4	*Workpiece*
U	1.5	***Expanded Uncertainty /µm***

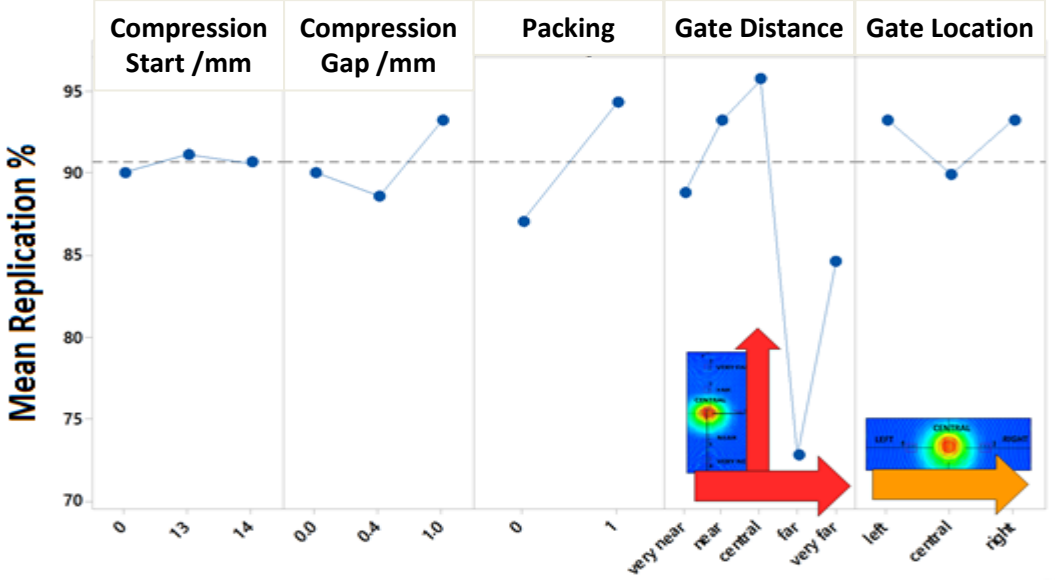
ub	0.0	*Background noise*
uc	0.1	*Calibration certificate*
up	0.3	***Procedure***
ub	0.0	*Uncertainty due to systematics*
u_{wp}	0.7	***Workpiece – process***
u_{wt}	0.0	*Workpiece – material*
u_w	0.7	*Workpiece*
U	1.6	***Expanded Uncertainty /µm***

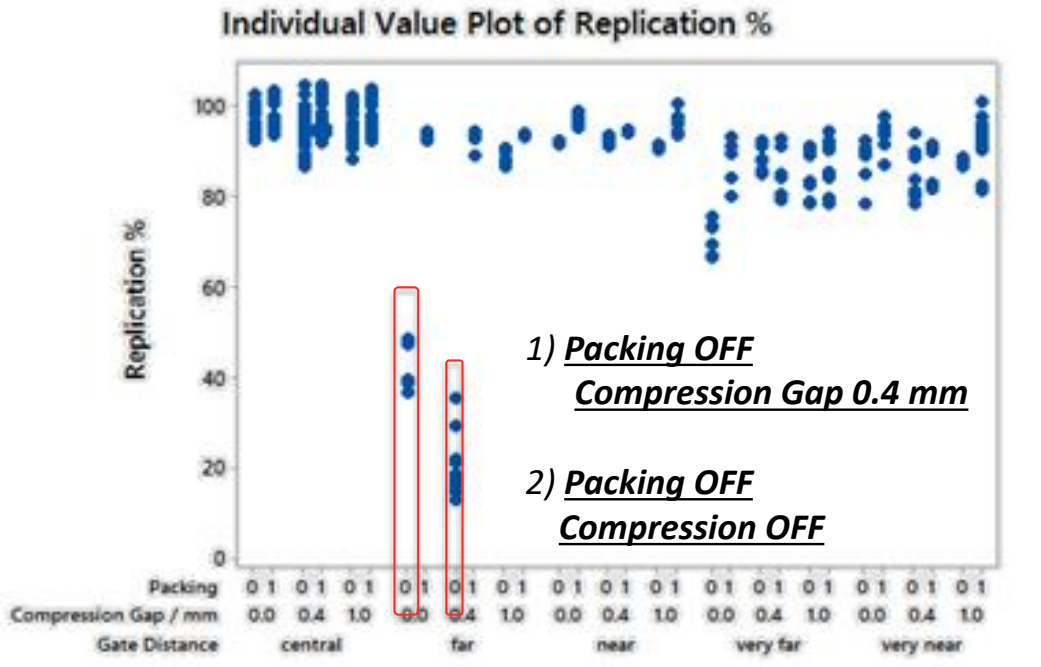
DOE 1 – COP ZEONEX © E48R:

Compression		Packing
Compression Starts @	Compression Gap	
13 - 14 [mm]	0.4 - 1 [mm]	ON/OFF
OFF	OFF	OFF
OFF	OFF	ON
13	0.4	OFF
14	0.4	OFF
13	1	OFF
14	1	OFF
13	0.4	ON
14	0.4	ON
13	1	ON
14	1	ON

DOE







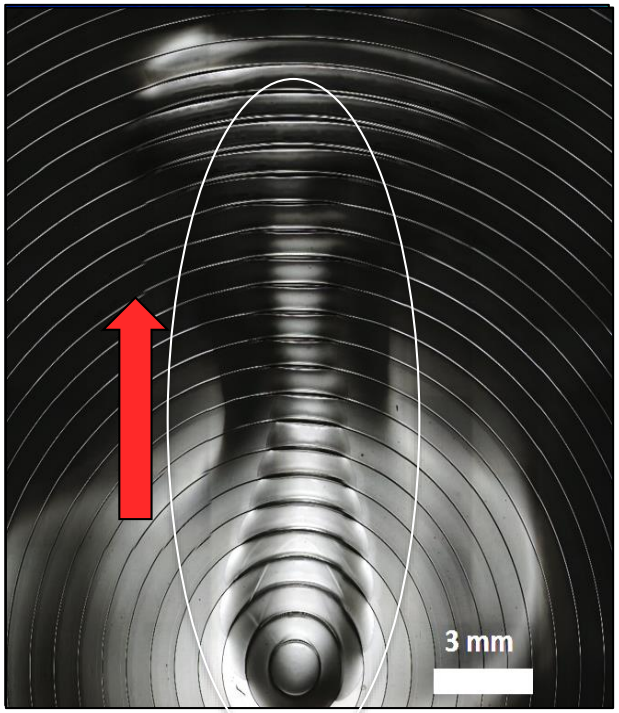
1) ***Packing OFF***
Compression Gap 0.4 mm

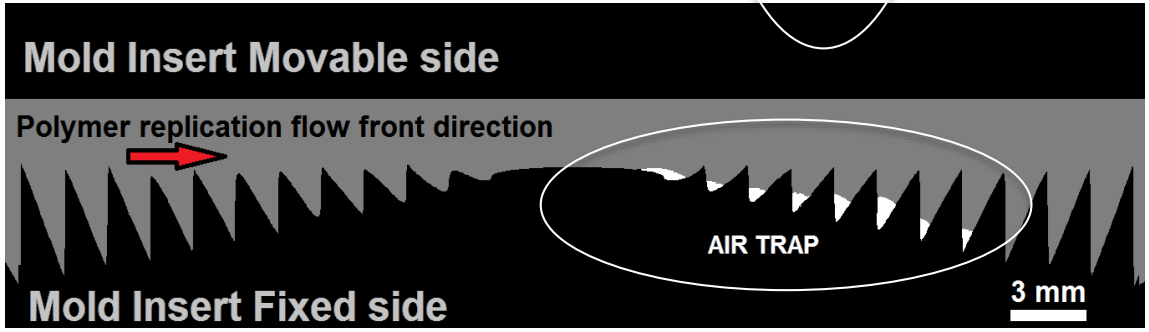
2) ***Packing OFF***
Compression OFF

DOE 1 – COP ZEONEX © E48R:

Compression		Packing
Compression Starts @	Compression Gap	
13 - 14 [mm]	0.4 - 1 [mm]	ON/OFF
OFF	OFF	OFF
OFF	OFF	ON
13	0.4	OFF
14	0.4	OFF
13	1	OFF
14	1	OFF
13	0.4	ON
14	0.4	ON
13	1	ON
14	1	ON

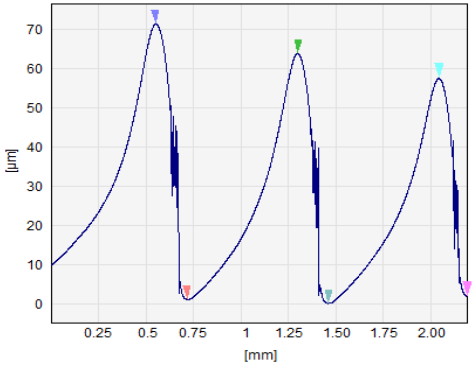
DOE





UNEXPELLED AIR

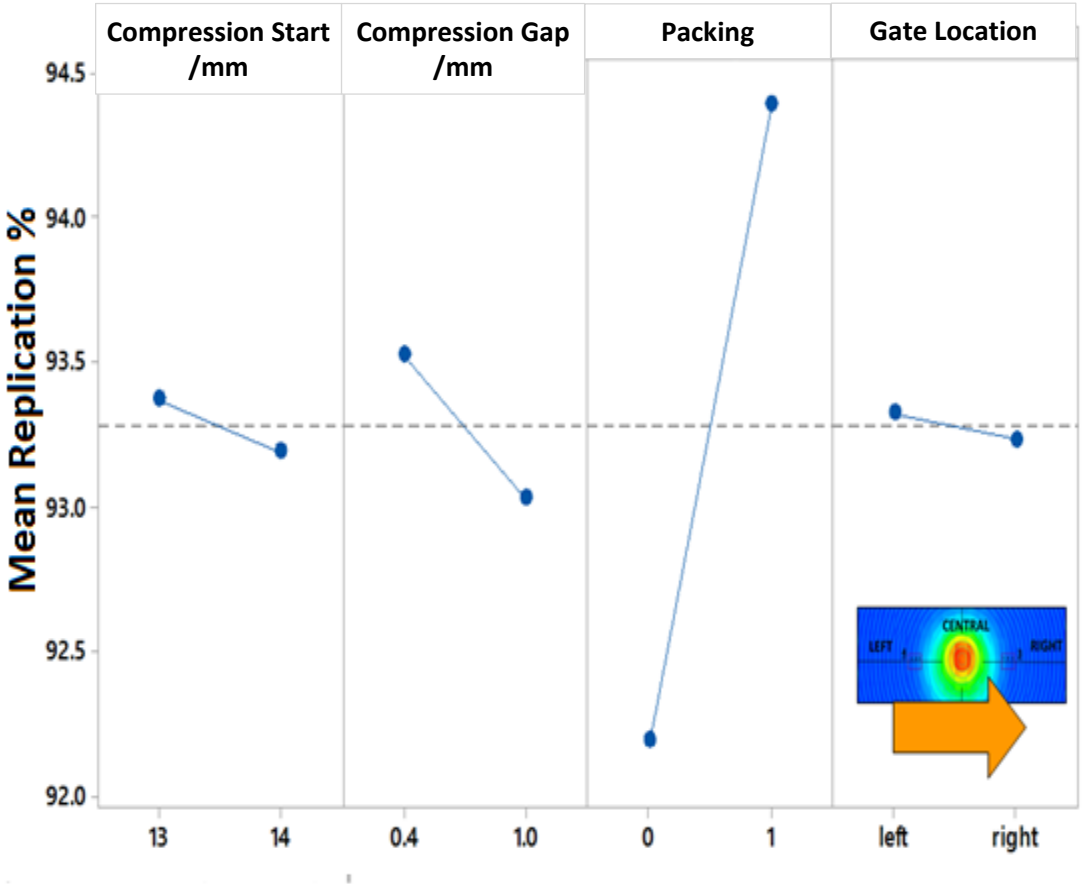
- **Slope of the Fresnel profile compared to the replication flow front**
- **Absence of a resolving packing phase**
- **Absence of a sufficient compression stroke**



DOE 1 – COP ZEONEX © E48R:

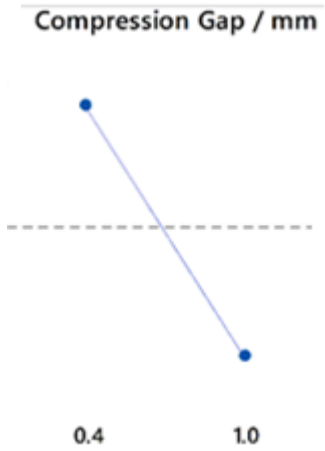
Compression		Packing
Compression Starts @	Compression Gap	
13 - 14 [mm]	0.4 - 1 [mm]	ON/OFF
OFF	OFF	OFF
OFF	OFF	ON
13	0.4	OFF
14	0.4	OFF
13	1	OFF
14	1	OFF
13	0.4	ON
14	0.4	ON
13	1	ON
14	1	ON

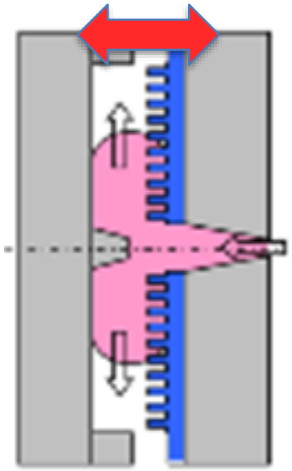
DOE



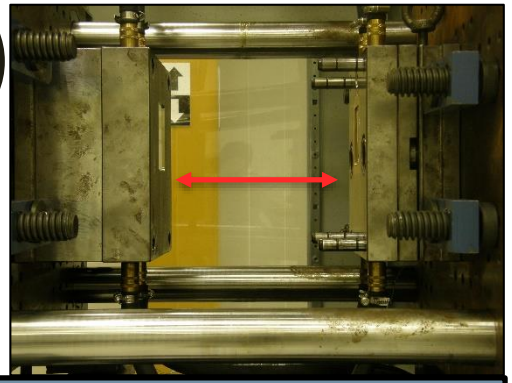
- ***Packing***
- ***Compression Gap***
- ***Symmetrical replication on the orthogonal direction of the polymer flow front***

Compression Gap:

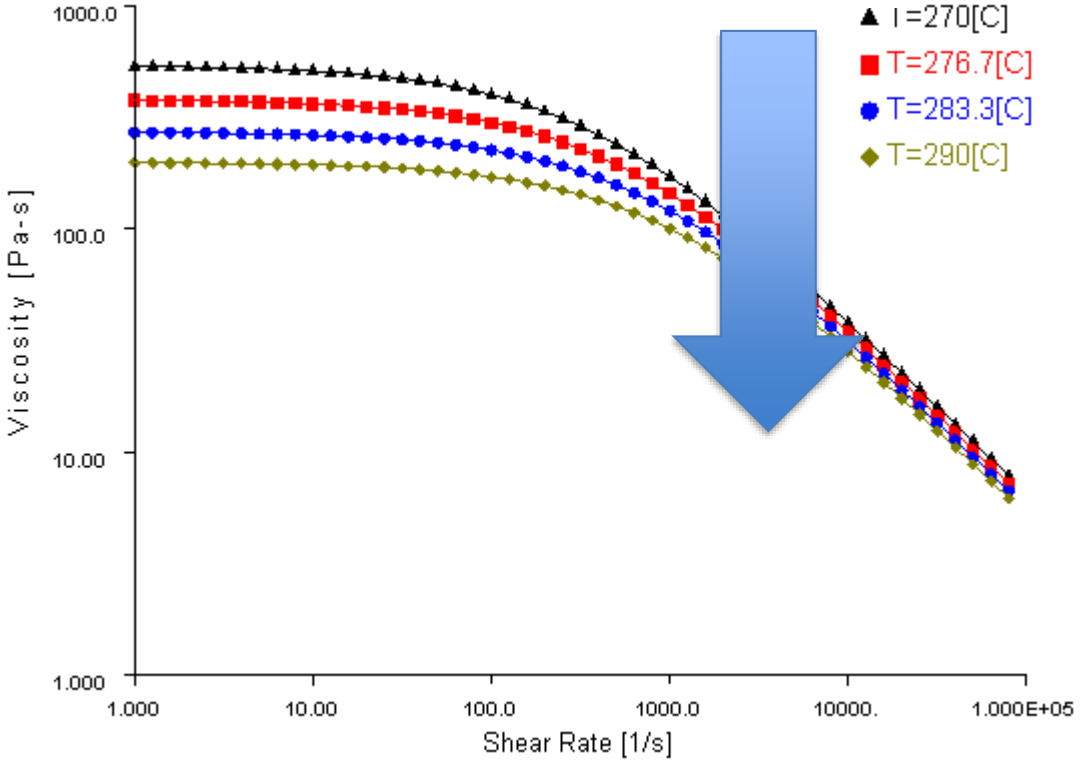




- ***High Compression Gap lowers replication quality***



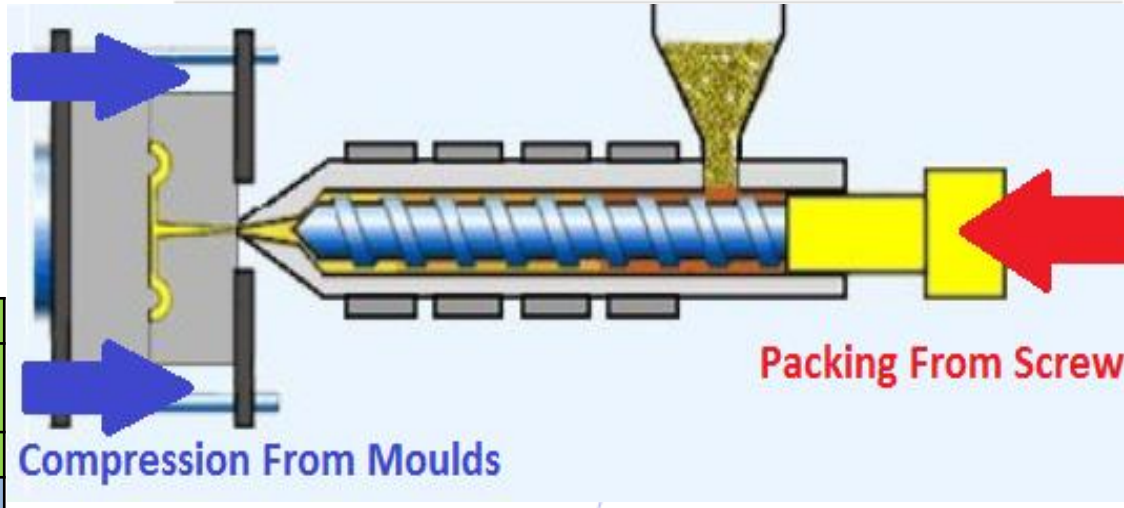
Results and conclusions



DOE 3 – COP ZEONEX © E48R:

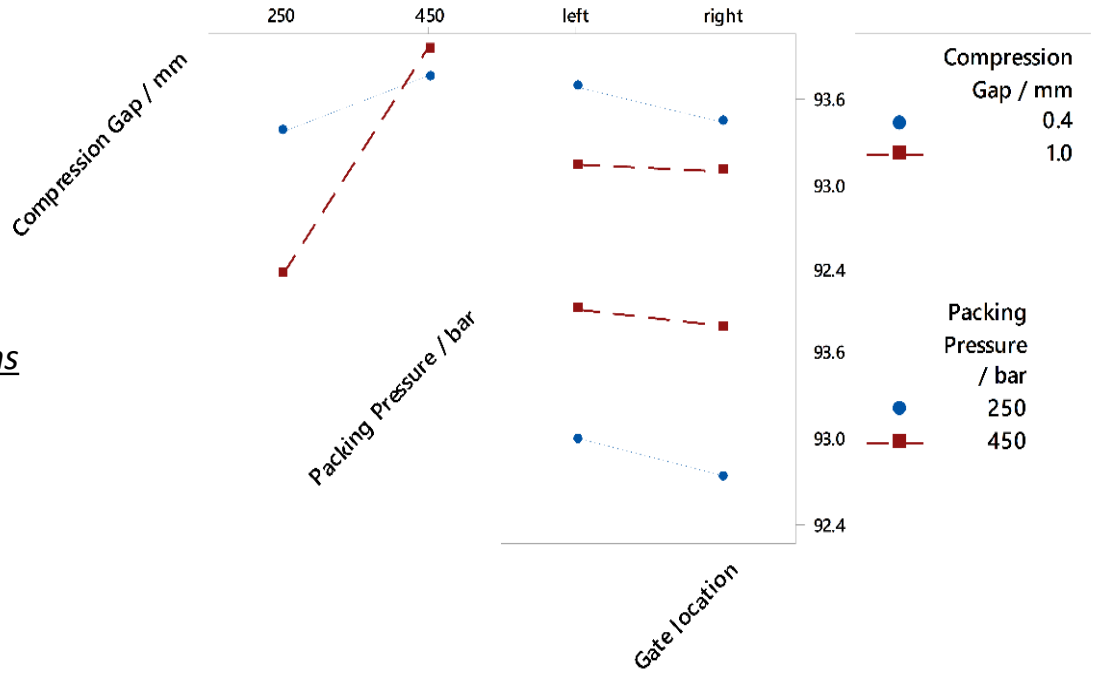
Compression	Packing
Compression Gap	Packing Pressure
0.4 - 1 [mm]	250 - 450 [bar]
0.4	OFF
1	OFF
0.4	450
1	450
0.4	250
1	250

DOE



Considering only the *central regions* of the lens, factors significance:

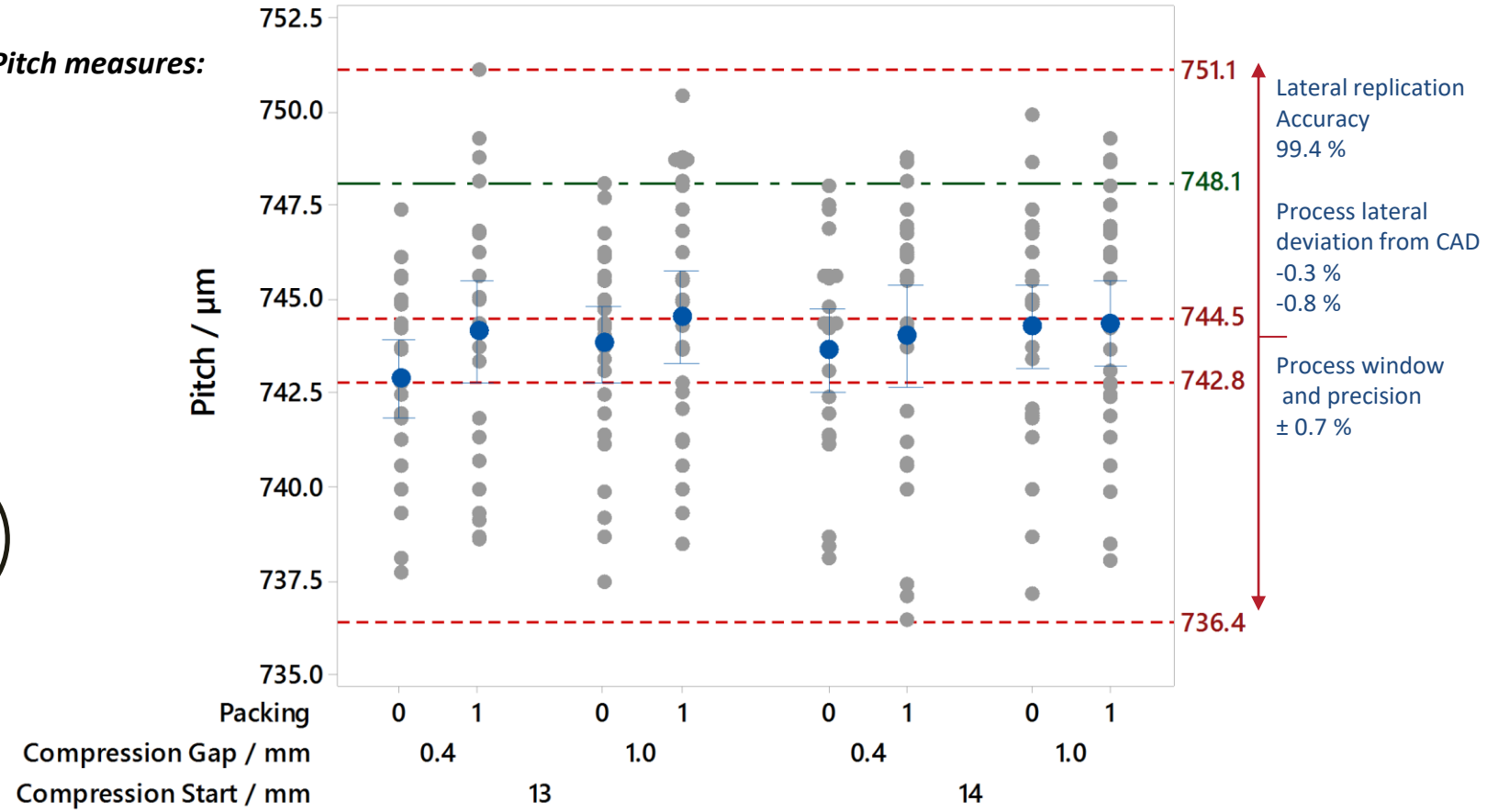
- ***Packing***
- ***Compression Gap***
- ***Packing* Compression Gap***



Results and conclusions

DOE 1 – COP ZEONEX © E48R:

Pitch measures:

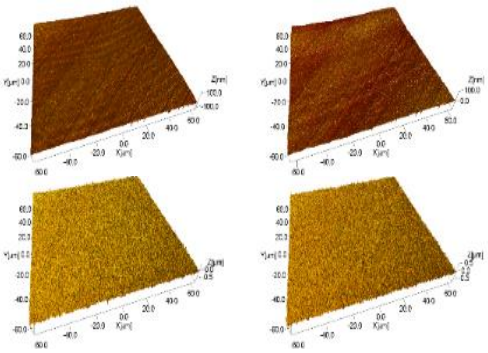


Pitch measures have highlighted *the **process window with an accuracy > 99 %***

Precision stays below ±1 %

Process factors requires further investigations

Summary:



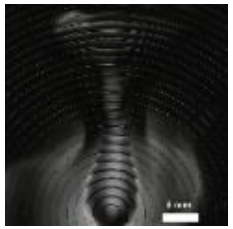
Results and conclusions

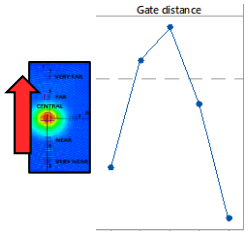
Established Metrological Routines:

- *Better performance of **standard objectives***
- *Validation of an **'on-sample' noise evaluation** procedure*
- *The dimensional lengths have been characterized with **uncertainty budgets** for both pitch and step height*

ICM optimization guidlines:

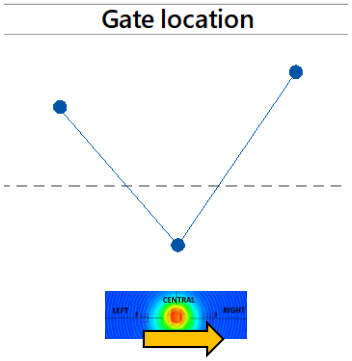
- *A **large scale defect** at far distance from the gate is a result of **air trap** due to the **absence of packing and insufficient compression stroke***
- ***Unbalanced replication** along the flow direction observed*

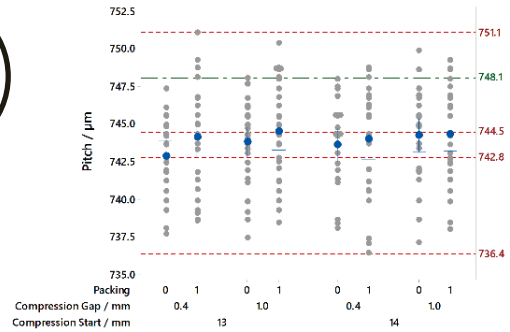




Results and conclusions

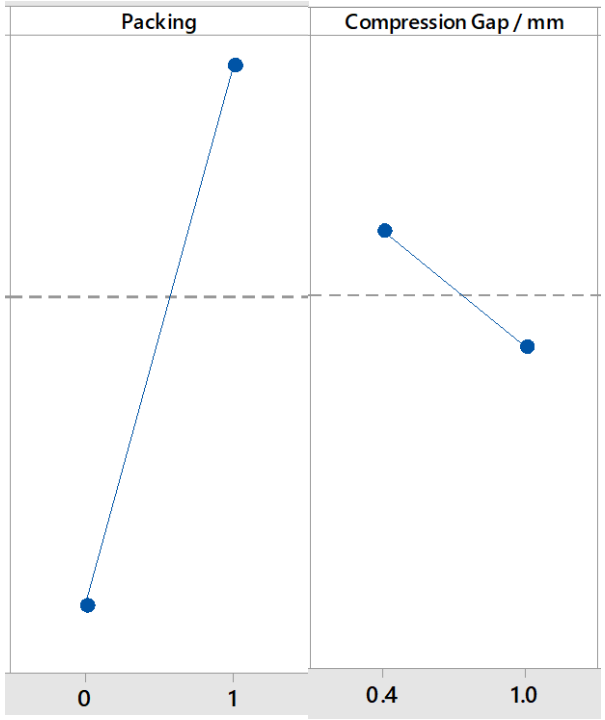
Summary:





On ICM optimization:

- ***Symmetrical replication*** *along the orthogonal direction of the flow direction at the lens centre verified*
- ***Packing*** *phase increases the replication average response*
- ***Compression*** *has not resolved the possibility to avoid a proper packing And must be optimized In accordance with* ***2nd Order interactions***
- *Pitch measures have identified the process lateral* ***replication accuracy > 99 % and precision < ± 1%***



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Results and conclusions

Future Work:

On metrology:

- *Surface roughness of the Fresnel lens have shown Sq values in the range of 10 nm. To verify this results the **use of a different instrument**, as an atomic force microscope*
- *A comparison of results with another processing software could indicate **possible limitations due to manual settings or implemented methodologies**, especially for pitch results*

On ICM:

- *A validation of the thermo-mechanical behaviour could be Proved by means of **process simulation** or pvt diagrams. This could also be an adequate troubleshooting to compensate and justify the large size defects*
- ***Functionality test** could be in a second room be performed to make a clear correlation between technological signature and optical functionality*

Thank you for your kind attention

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Appendix – Anova Tables DOE1

General Linear Model: Replication % Ou versus Compression Star, Compression Gap , Packing

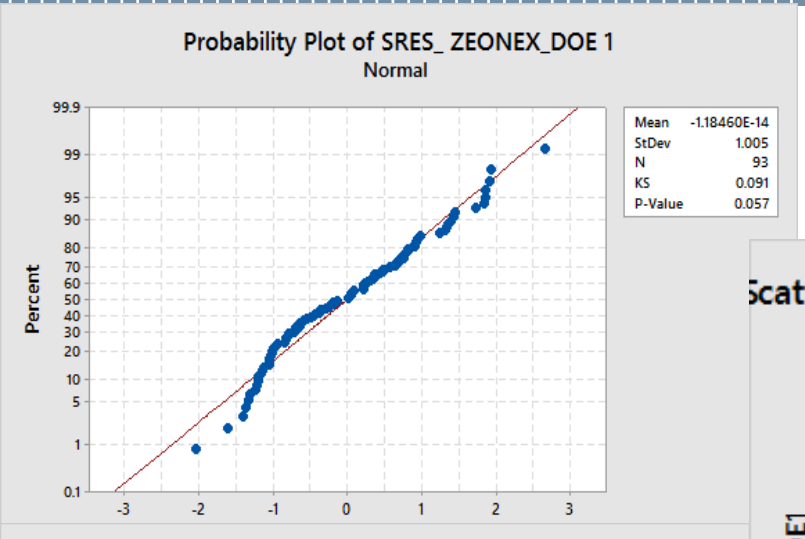
Analysis of Variance

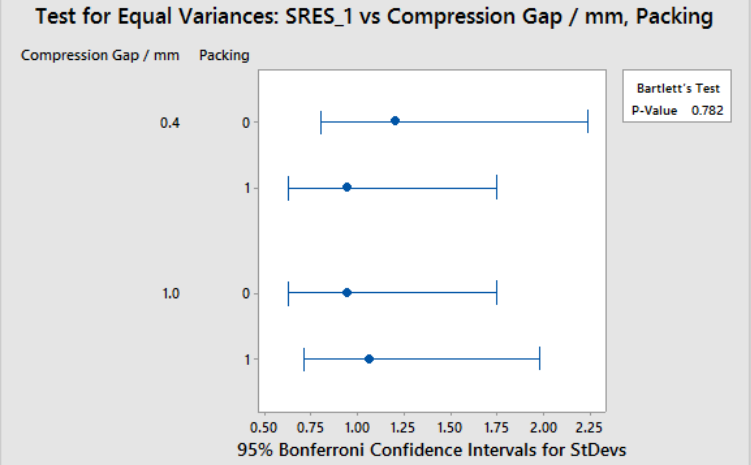
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Compression Starts @ / mm	1	0.473	0.473	0.75	0.388
Compression Gap / mm	1	5.975	5.975	9.53	0.003
Packing	1	112.980	112.980	180.24	0.000
Compression Gap / mm*Packing	1	2.135	2.135	3.41	0.068
Error	88	55.161	0.627		
Lack-of-Fit	27	8.940	0.331	0.44	0.990
Pure Error	61	46.221	0.758		
Total	92	176.207			

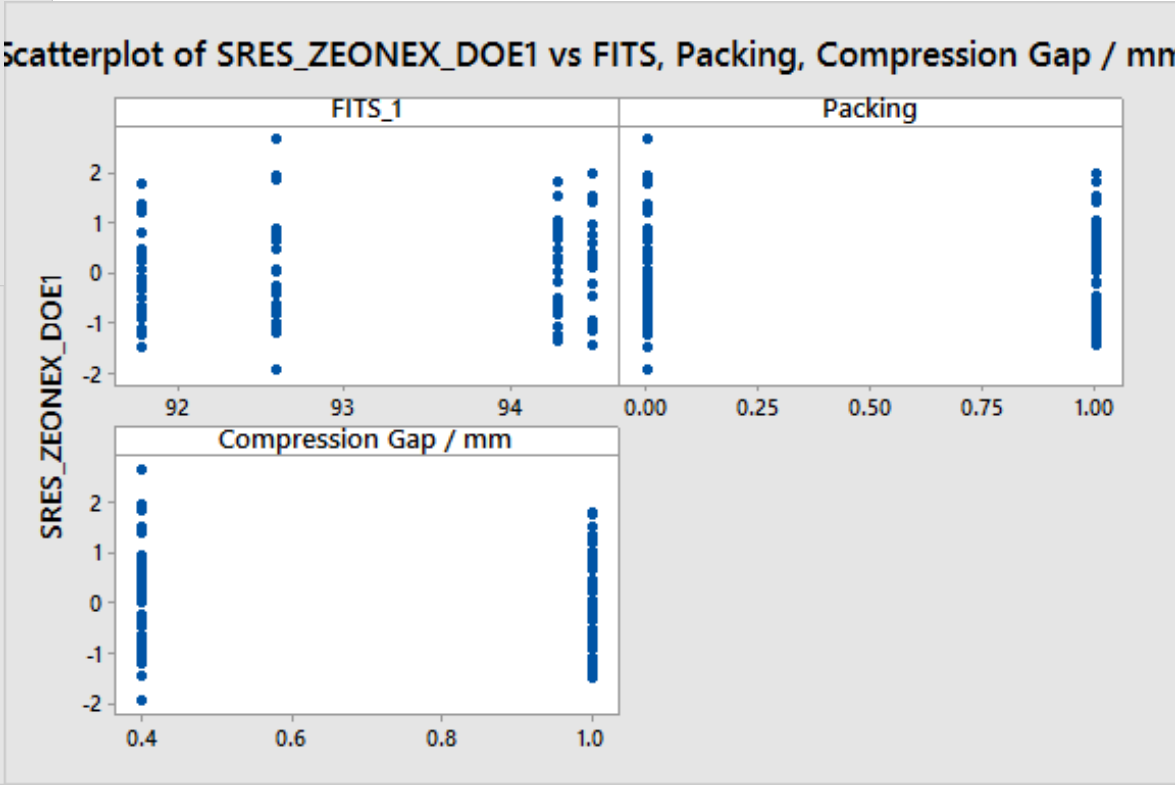
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.791729	68.70%	67.27%	65.05%

Appendix – Anova Tables DOE1







Appendix – Anova Tables DOE3

General Linear Model: Replication versus Compression , Packing Pres, Gate locatio

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Compression Gap / mm	1	1.1893	1.18925	19.69	0.000
Packing Pressure / bar	1	7.5502	7.55017	125.03	0.000
Gate location	1	0.3190	0.31896	5.28	0.030
Compression Gap / mm*Packing Pressure / bar	1	2.8140	2.81400	46.60	0.000
Error	26	1.5701	0.06039		
Lack-of-Fit	3	0.0689	0.02298	0.35	0.788
Pure Error	23	1.5012	0.06527		
Total	30	13.3735			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.245740	88.26%	86.45%	83.31%

Appendix – Anova Tables DOE3