

MINISTÉRIO DAS OBRAS PÚBLICAS, TRANSPORTES E COMUNICAÇÕES
Laboratório Nacional de Engenharia Civil

Departamento de Materiais

Proc. 0204/11/16162

Proc. 0204/75/8104

QUALANOD INTER-LABORATORY TESTS OF ANODIZED ALUMINIUM TESTING METHODS
STATISTICAL ANALYSIS - DETERMINATION OF REPEATABILITY AND REPRODUCIBILITY
REPORT 297/2006 - DM

Lisboa, Outubro 2006

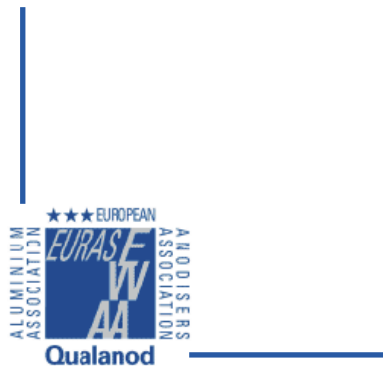
Trabalho realizado para

QUALANOD (EURAS/EWAA)



QUALANOD INTER-LABORATORY TEST OF ANODIZED ALUMINIUM TESTING METHODS

STATISTICAL ANALYSIS - REPEATIBILITY AND REPRODUCIBILITY DETERMINATION





Institutions/laboratories that intended to participate in this inter-laboratory test

| Country | Name | Laboratory |
|-------------|--|-------------|
| AUSTRIA | Aluminium Ranshofen Service GmbH | AMAG |
| BELGIUM | CORI - Coatings Research Institute | CoRI |
| FRANCE | TESTAL | - |
| GERMANY | IFO GmbH - Institut für Oberflächentechnik | IO GmbH |
| GREECE | AAG Quality – EKANAL for Aluminium Ass. Of Greece | EKANAL |
| HUNGARY | ÉMI KHT - Institut für Qualitätskontrolle | ÉMI KHT |
| ITALY | QUALITAL | QUALITAL |
| NETHERLANDS | Adviescentrum VOM B.H. | A VOM B. V. |
| POLAND | Instytut Mechaniki Precyzyjnej | IMP |
| PORTUGAL | LNEC - Laboratório Nacional de Engenharia Civil | LNEC |
| SPAIN | QUALESPAÑA - Ministerio de Vivienda Subdirección General de Innovación y Calidad de la Edificación | CEDEX |
| SWITZERLAND | EMPA, Abtl. Korrosion | EMPA |
| TURKEY | Turkish Standards Institution | - |

Laboratories from Turkey and France haven't sent any results

Testing methods

- **EN ISO 2360:2003** - *Non-conductive coatings on non-magnetic electrically conductive basis materials. **Measurement of coating thickness.** Amplitude-sensitive eddy current method (ISO 2360:2003)*
- **EN 12373-7:2002** (2ndEd.) - *Aluminium and aluminium alloys. Anodizing. Part 7: Assessment of **quality of sealed anodic oxidation coatings by measurement of the loss of mass** after immersion in phosphoric acid/chromic acid solution with prior acid treatment*
- **EN 12373-5:1998** - *Aluminium and aluminium alloys. Anodizing. Part 5: Assessment of **quality of sealed anodic oxidation coatings by measurement of admittance***
- **EN 12373-4:1998** - *Aluminium and aluminium alloys. Anodizing. Part 4: Estimation of loss absorptive power of anodic oxidation coatings after sealing by **dye spot test** with prior acid treatment*



General characteristics of the test specimens

| ALUMINIUM | Alloy Type | Type of product | Dimensions of testing specimens | |
|------------------|------------|------------------------------|---------------------------------|---------|
| | 6060 | Sheet with 1 mm of thickness | 70mmx140 mm | |
| ANODIC COATING | Type | Thickness class | Sealing | Colour |
| Polished surface | P | 15 μm | 3 min/ μm | natural |
| | IP | 15 μm | not sealed | natural |
| | I | 25 μm | 1 min/ μm | bronze |
| Satined surface | A | 20 μm | 3 min/ μm | natural |

Fifty specimens of each coating type were produced

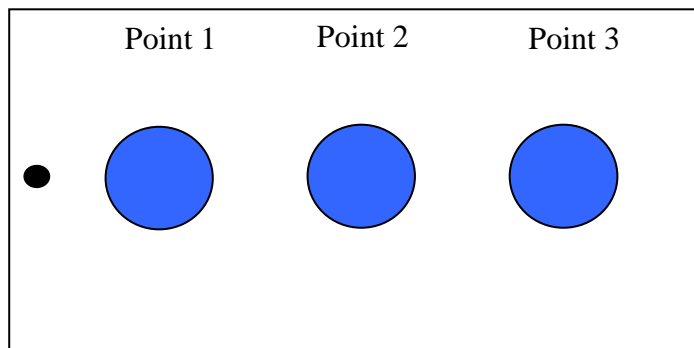


Anodizing and sealing conditions used for the production of test specimens

| Coating type | Anodizing bath | | Sealing bath | |
|--------------|---------------------------------------|-----------------------|---------------------|------------|
| P | Free H ₂ SO ₄ - | 184,7 g/l | Demineralised water | |
| | Al content - | 12,8 g/l | pH - | 5,70 |
| | Temperature - | 18,0 °C | Additive - | Anodal SH1 |
| | Current density - | 1,6 A/dm ² | Time - | 3 min/μm |
| I | Free H ₂ SO ₄ - | 182,1 g/l | Demineralised water | |
| | Al content - | 11,4 g/l | pH - | 5,75 |
| | Temperature - | 19,0 °C | Additive - | Anodal SH1 |
| | Current density - | 1,7 A/dm ² | Time - | 1 min/μm |
| IP | Free H ₂ SO ₄ - | 184,7 g/l | Not sealed | |
| | Al content - | 12,8 g/l | | |
| | Temperature - | 19,0 °C | | |
| | Current density - | 1,6 A/dm ² | | |
| A | Free H ₂ SO ₄ - | 184,7 g/l | Demineralised water | |
| | Al content - | 12,8 g/l | pH - | 5,70 |
| | Temperature - | 19,0 °C | Additive - | Anodal SH1 |
| | Current density - | 1,7 A/dm ² | Time - | 3 min/μm |

Instructions

- Laboratory code number
- Measuring points

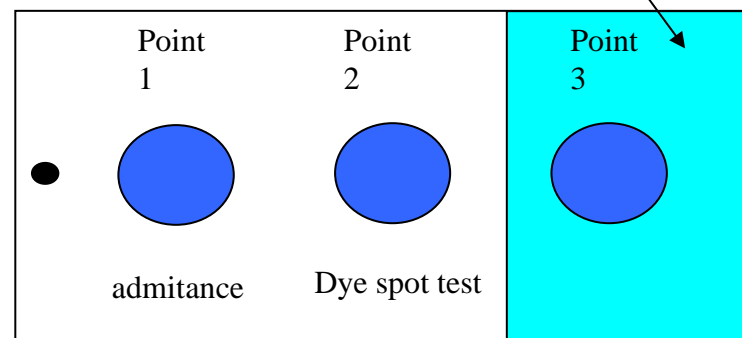


Scheme of the testing zones for thickness measurement



Sample with 70mmX50mm for sealing assessment by the mass loss test

Scheme of testing zones for sealing quality assessment





EXCEL Worksheets for data registration

Protocol

| | |
|------------------|----------|
| Test laboratory: | LNEC |
| Sample type: | P |
| Tested by: | N Garcia |
| Date of report: | |

Test conditions

| | | | |
|------------------------|------------|-------|------------|
| Temperature: | 21 | ± 2 | °C |
| Date of the test: | 05-12-2005 | | yyyy-mm-dd |
| Zero base | 0,0 | ± | µm |
| Calibration standard 1 | 23,5 | ± 0,5 | µm |
| Calibration standard 2 | | ± | µm |
| Calibration standard 3 | | ± | µm |

Test results

Thickness results (ISO 2360)

| Sample No. | Front side (µm) | | | |
|--------------------------|-----------------|-----------|-----------|-------------|
| | 1st point | 2nd point | 3rd point | |
| P15 | | | | |
| measure 1 | 21,6 | | | |
| measure 2 | 22,0 | | | |
| measure 3 | 21,3 | | | |
| Average thickness | 21,6 | | | 21,6 |

Weight loss results (EN 12373-7)

| Sample No. | Height H | Lenght L | Sample thickness T | Area A | Weigth loss |
|----------------|--------------|--------------|--------------------|--------------------|-----------------------|
| | (mm) | (mm) | (mm) | (dm ²) | (mg/dm ²) |
| P15 | | | | | |
| measure 1 | 71,59 | 50,29 | 1,04 | - | - |
| measure 2 | 71,34 | 50,86 | 1,05 | - | - |
| measure 3 | 71,83 | 51,08 | 1,03 | - | - |
| Average | 71,59 | 50,74 | 1,04 | 0,7506 | 15 |

Admittance results (EN 12373-5)

| Sample No. | Measurement | Thickness | Temperature | Admittance |
|------------|-------------|-----------|-------------|------------|
| | Ym | (µm) | (°C) | Y |
| P15 | | | | |
| | 10,5 | 24,6 | 21,2 | 8,0 |

Dye spot results (EN 12373-4)

| | |
|----------|-----|
| Dye spot | 0-1 |
|----------|-----|

| Sample No. | Front side (µm) | | | |
|--------------------------|-----------------|-----------|-----------|--|
| | 1st point | 2nd point | 3rd point | |
| | | | | |
| measure 1 | | | | |
| measure 2 | | | | |
| measure 3 | | | | |
| Average thickness | | | | |

| Sample No. | Height H | Lenght L | Sample thickness T | Area A | Weigth loss |
|----------------|----------|----------|--------------------|--------------------|-----------------------|
| | (mm) | (mm) | (mm) | (dm ²) | (mg/dm ²) |
| P15 | | | | | |
| measure 1 | | | | - | - |
| measure 2 | | | | - | - |
| measure 3 | | | | - | - |
| Average | | | | | |

| Sample No. | Measurement | Thickness | Temperature | Admittance |
|------------|-------------|-----------|-------------|------------|
| | Ym | (µm) | (°C) | Y |
| | | | | |

| | |
|----------|--|
| Dye spot | |
|----------|--|

| Sample No. | Front side (µm) | | | |
|--------------------------|-----------------|-----------|-----------|--|
| | 1st point | 2nd point | 3rd point | |
| | | | | |
| measure 1 | | | | |
| measure 2 | | | | |
| measure 3 | | | | |
| Average thickness | | | | |

| Sample No. | Height H | Lenght L | Sample thickness T | Area A | Weigth loss |
|----------------|----------|----------|--------------------|--------------------|-----------------------|
| | (mm) | (mm) | (mm) | (dm ²) | (mg/dm ²) |
| | | | | - | - |
| measure 1 | | | | - | - |
| measure 2 | | | | - | - |
| measure 3 | | | | - | - |
| Average | | | | | |

| Sample No. | Measurement | Thickness | Temperature | Admittance |
|------------|-------------|-----------|-------------|------------|
| | Ym | (µm) | (°C) | Y |
| | | | | |

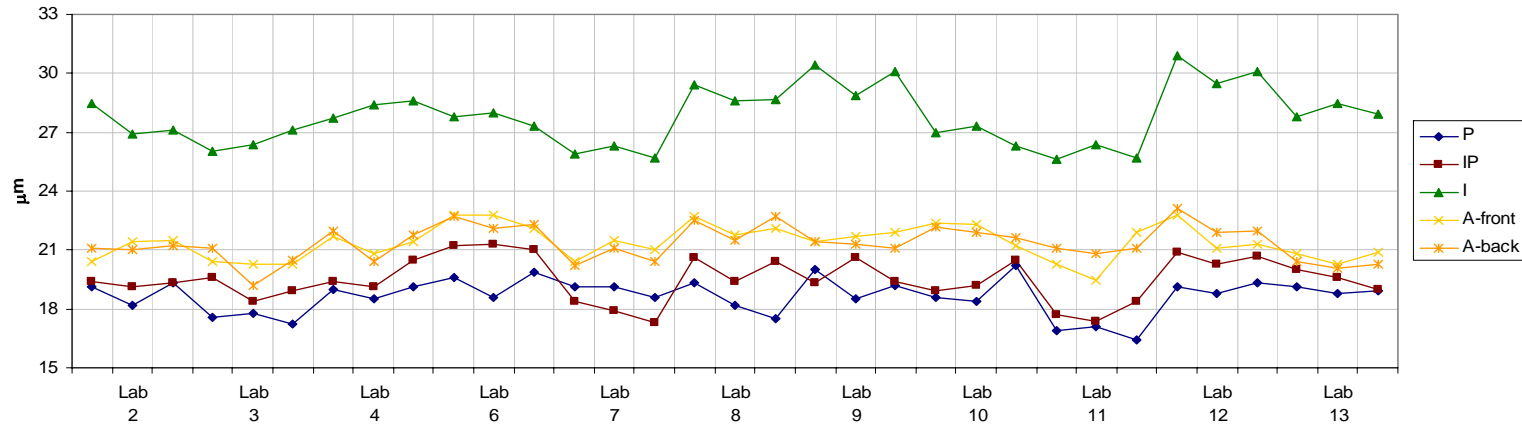
| | |
|----------|--|
| Dye spot | |
|----------|--|

Example for the registration of tests results for specimens of coating type P

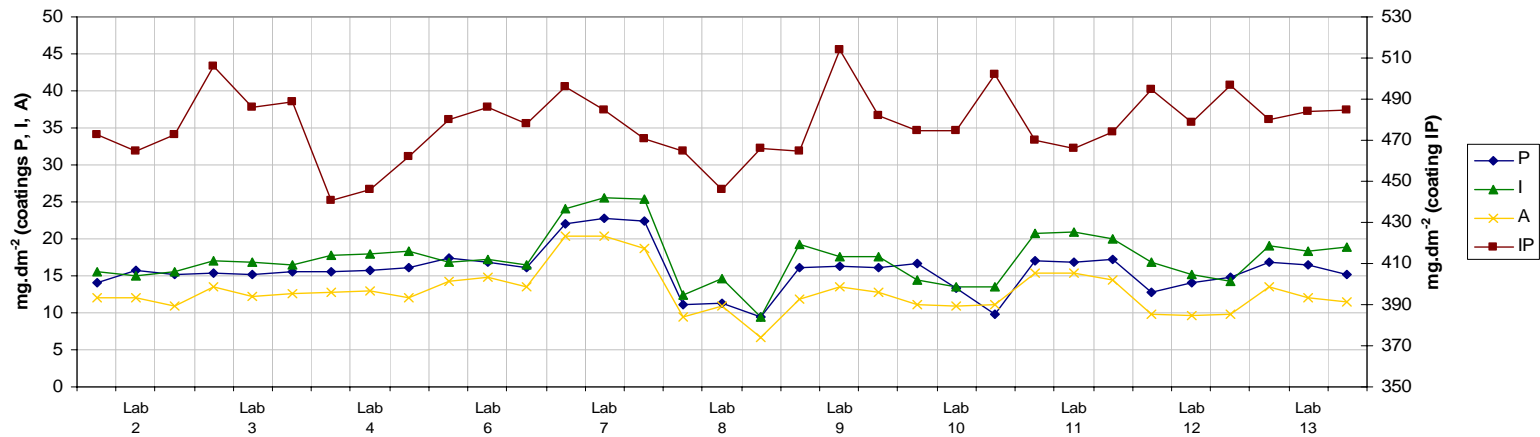
Results reported



Test results of method EN ISO 2360



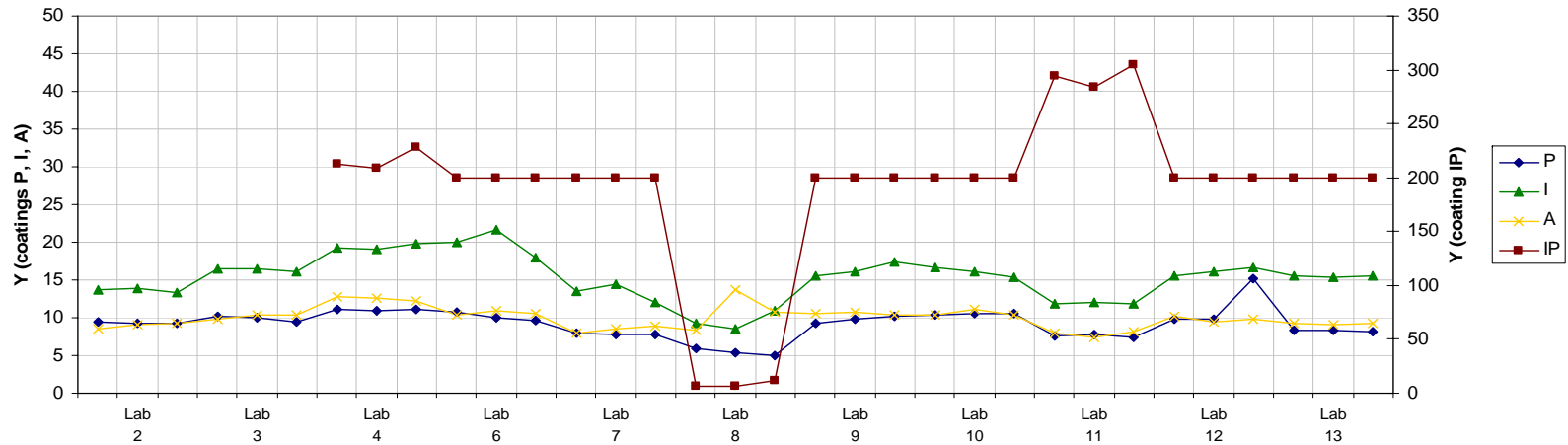
Test results of method EN 12373-7



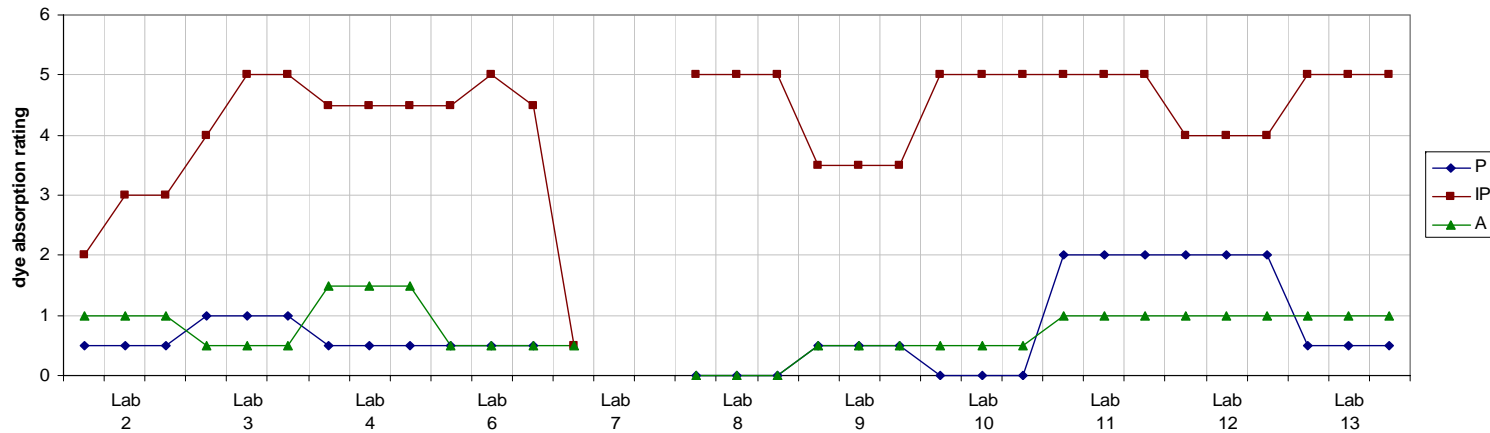
Results reported



Test results of method EN 12373-5



Test results of method EN 12373-4





Precision analysis according to ISO 5725-2

- Consistency tests
 - Graphical consistency technique – Mandel's h and k statistics

$$h_{ij} = \frac{\bar{y}_{ij} - \bar{y}_j}{\sqrt{\frac{1}{(p_j - 1)} \sum (\bar{y}_{ij} - \bar{y}_j)^2}} \quad k_{ij} = \frac{s_{ij} \sqrt{p_j}}{\sqrt{\sum s_{ij}^2}}$$

- Numerical outlier technique – Cochran's and Grubb's tests

$$C = \frac{s_{max}^2}{\sum_{i=1}^p s_i^2}$$

$$G_p = (x_p - \bar{x})/s$$

$$G_1 = (\bar{x} - x_1)/s$$

$$G = s_{p-1,p}^2 / s_0^2$$

$$G = s_{1,2}^2 / s_0^2$$

- Calculation of the **general mean and variances**

$$\hat{m}_j = \bar{y}_j = \frac{\sum_{i=1}^p n_{ij} \bar{y}_{ij}}{\sum_{i=1}^p n_{ij}}$$

$$s_{ij}^2 = \frac{\sum_{i=1}^p (n_{ij} - 1) s_{ij}^2}{\sum_{i=1}^p (n_{ij} - 1)}$$

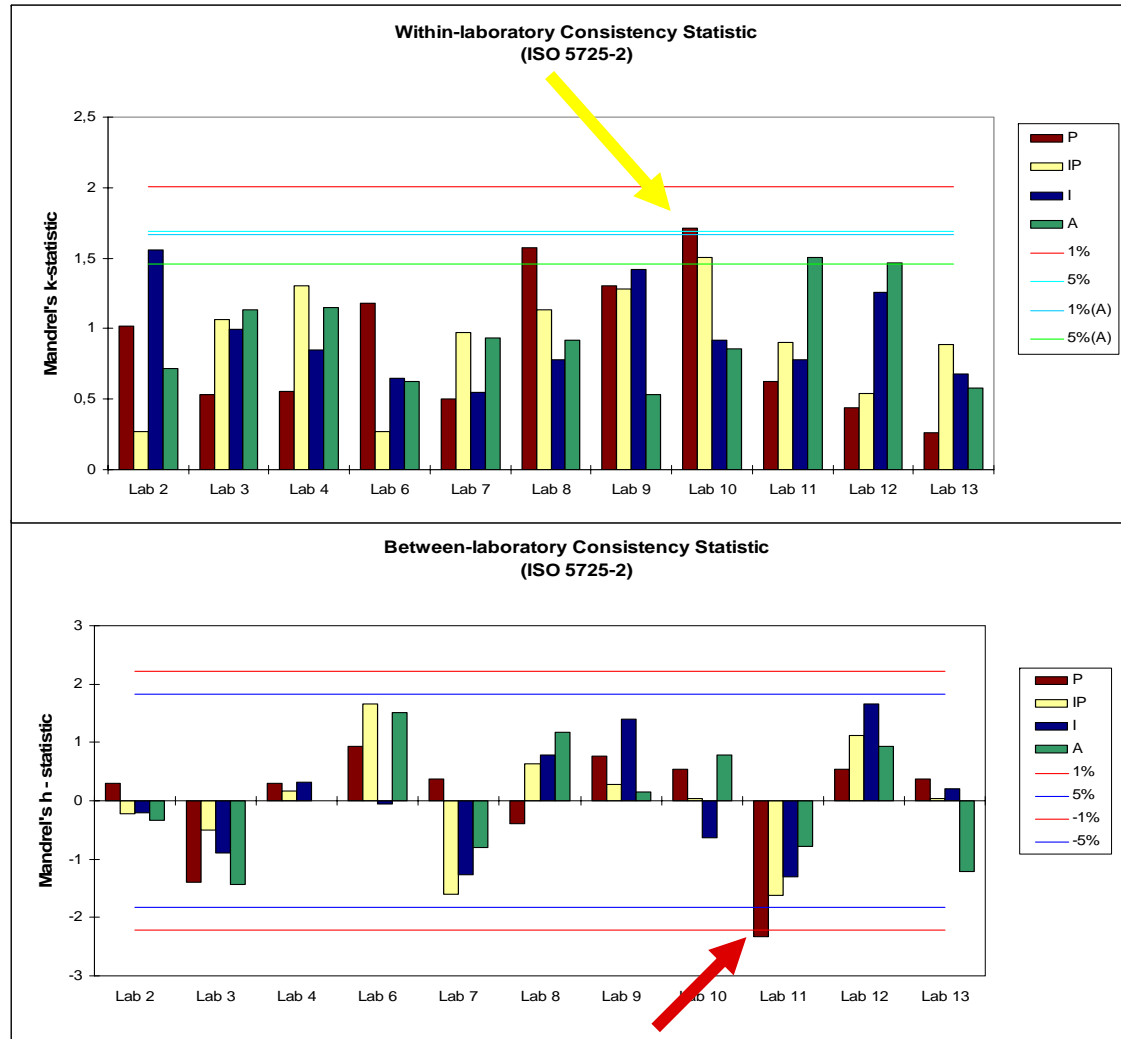
Repeatability variance

$$s_{Rj}^2 = s_{ij}^2 + s_{Lj}^2$$

Reproducibility variance

$$\left[s_{dj}^2 = \frac{1}{p-1} \sum_{i=1}^p n_{ij} (\bar{y}_{ij} - \bar{y}_j)^2 = \frac{1}{p-1} \left[\sum_{i=1}^p n_{ij} (\bar{y}_{ij})^2 - (\bar{y}_j)^2 \sum_{i=1}^p n_{ij} \right] \right]$$

Thickness measurement (EN ISO 2360)



Thickness measurement (EN ISO 2360)



Laboratories outside critical value lines of Mandel's statistics

| Level | P | IP | I | A |
|-------------------------|-----------|----|---|----------------|
| Mandel's <i>k</i> -plot | Lab 10 | - | - | Lab 11; Lab 12 |
| Classification | Straggler | - | - | Straggler |
| Mandel's <i>h</i> -plot | Lab 11 | - | - | - |
| Classification | Outlier | - | - | - |

Cochran's test results

| Level | P | IP | I | A |
|------------------------------------|---------|---------|---------|---------|
| Valid laboratories <i>p</i> | 11 | 11 | 11 | 11 |
| Number of replicates <i>n</i> | 3 | 3 | 3 | 6 |
| 1% Critical value $C_{Cr} (1\%)$ | 0,504 | 0,504 | 0,504 | 0,332 |
| 5% Critical value $C_{Cr} (5\%)$ | 0,417 | 0,417 | 0,417 | 0,281 |
| Cochran's test statistic C | 0,266 | 0,148 | 0,222 | 0,206 |
| Classification | correct | correct | correct | correct |
| Outlier Lab ($C > C_{Cr} (1\%)$) | - | - | - | - |



Thickness measurement (EN ISO 2360)

Grubb's test results

| Level | P | IP | I | A |
|---|----------------------|----------------|----------------|----------------|
| Valid laboratories p | 11 | 11 | 11 | 11 |
| Single G_{Cr} (1%) | 2,564 | 2,564 | 2,564 | 2,564 |
| Single G_{Cr} (5%) | 2,355 | 2,355 | 2,355 | 2,355 |
| Single high G_p | 0,926 | 1,650 | 1,658 | 1,512 |
| Single low G_1 | 2,328 | 1,627 | 1,308 | 1,430 |
| Classification (low) | <i>correct</i> | <i>correct</i> | <i>correct</i> | <i>correct</i> |
| Outlier Lab ($G_p > G_{Cr}$ (1%)) | - | - | - | - |
| Classification (low) | <i>correct</i> | <i>correct</i> | <i>correct</i> | <i>correct</i> |
| Outlier Lab ($G_1 > G_{Cr}$ (1%)) | - | - | - | - |
| Double G_{Cr} (1%) | 0,1448 | 0,1448 | 0,1448 | 0,1448 |
| Double G_{Cr} (5%) | 0,2213 | 0,2213 | 0,2213 | 0,2213 |
| Double high $G_{largest}$ | 0,826 | 0,5152 | 0,4244 | 0,5539 |
| Double low $G_{smallest}$ | 0,1084 | 0,3662 | 0,5964 | 0,5738 |
| Classification (two largest) | <i>correct</i> | <i>correct</i> | <i>correct</i> | <i>correct</i> |
| Outlier Lab ($G_{largest} < G_{Cr}$ (1%)) | - | - | - | - |
| Classification (two smallest) | Outliers | <i>correct</i> | <i>correct</i> | <i>correct</i> |
| Outlier Lab ($G_{smallest} < G_{Cr}$ (1%)) | Lab 3; Lab 11 | - | - | - |

Single: test for one outlying observation; Double: test for two outlying observations

Thickness measurement (EN ISO 2360)

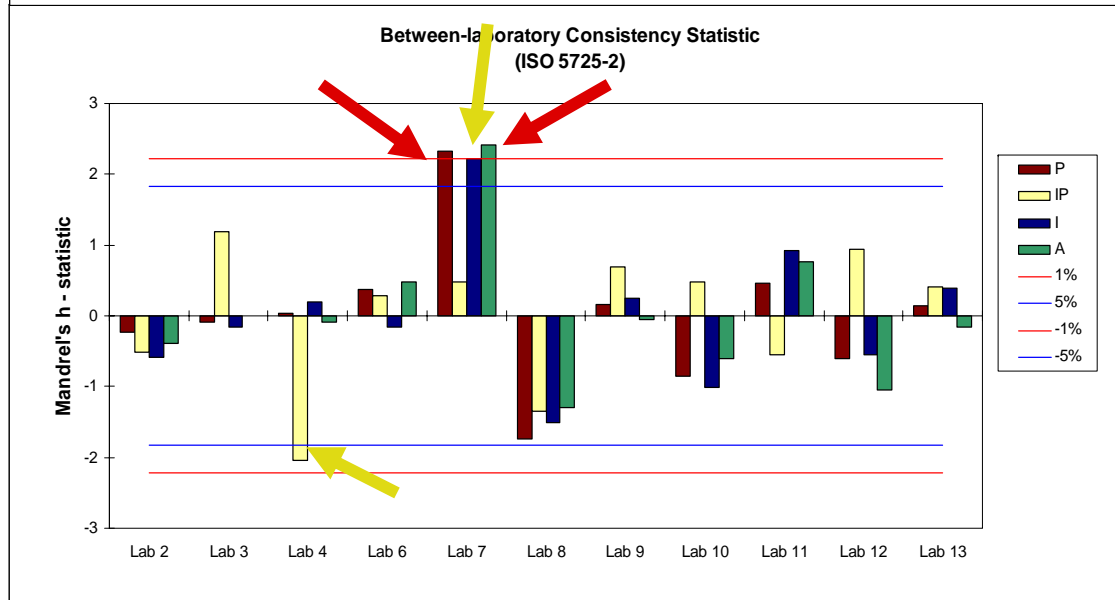
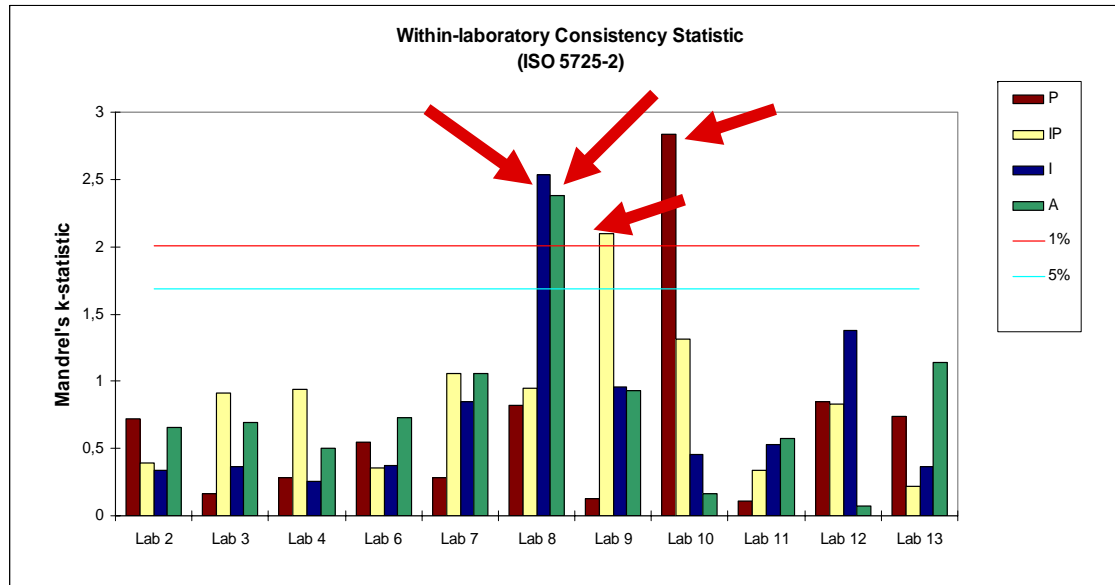


Results of precision analysis

| Level | P | IP | I | A |
|---|---|--------------|--------------|--------------|
| Number of replicates n | 3 | 3 | 3 | 6 |
| Valid laboratories p | 11 | 11 | 11 | 11 |
| General mean $m / \mu\text{m}$ | 18,64 | 19,49 | 27,78 | 21,35 |
| Repeatability variance s_r^2 | 0,333 | 0,321 | 0,312 | 0,294 |
| Between-lab variance s_L^2 | 0,511 | 0,928 | 1,966 | 0,493 |
| Reproducibility variance s_R^2 | 0,844 | 1,248 | 2,278 | 0,788 |
| Repeatability std. dev. s_r | 0,58 | 0,57 | 0,56 | 0,54 |
| Reproducibility std. dev. s_R | 0,92 | 1,12 | 1,51 | 0,89 |
| Repeatability COV (s_r/m) | 3,1% | 2,9% | 2,0% | 2,5% |
| Reproducibility COV (s_R/m) | 4,9% | 5,7% | 5,4% | 4,2% |
| Number of outliers | 2 | 0 | 0 | 0 |
| Number of excluded outliers | 0 | 0 | 0 | 0 |
| Outlier type | ¹ Mh, ² G(II) | - | - | - |
| Outlier laboratories | Lab 3 ² Lab 11 ^{1,2} | - | - | - |

Outlier type: Mh – Mandel's h ; Mk – Mandel's k ; C - Cochran's; G(I) – Grubs (one outlying observation); G(II) – Grubs (two outlying observations)

Sealing quality assessment by mass loss (EN 12373-7)



Sealing quality assessment by mass loss (EN 12373-7)



Laboratories outside critical value lines of **Mandel's** statistics

| Level | P | IP | I | A |
|------------------------|----------------|------------------|------------------|----------------|
| <i>Mandel's k-plot</i> | Lab 10 | Lab 9 | Lab 8 | Lab 8 |
| Classification | <i>Outlier</i> | <i>Outlier</i> | <i>Outlier</i> | <i>Outlier</i> |
| <i>Mandel's h-plot</i> | Lab 7 | Lab 4 | Lab 7 | Lab 7 |
| Classification | <i>Outlier</i> | <i>Straggler</i> | <i>Straggler</i> | <i>Outlier</i> |

Cochran's test results

| Level | P | IP | I | A |
|-----------------------------------|----------------|----------------|----------------|----------------|
| Valid laboratories p | 11 | 11 | 11 | 11 |
| Number of replicates n | 3 | 3 | 3 | 3 |
| 1% Critical value $C_{Cr(1\%)}$ | 0,504 | 0,504 | 0,504 | 0,504 |
| 5% Critical value $C_{Cr(5\%)}$ | 0,417 | 0,417 | 0,417 | 0,417 |
| Cochran's test statistic C | 0,731 | 0,400 | 0,583 | 0,515 |
| Classification | <i>Outlier</i> | <i>correct</i> | <i>Outlier</i> | <i>Outlier</i> |
| Outlier Lab ($C > C_{Cr(1\%)}$) | Lab 10 | - | Lab 8 | Lab 8 |

Sealing quality assessment by mass loss (EN 12373-7)



Grubb's test results

| Level | P | IP | I | A |
|---|----------------|----------------|----------------|------------------|
| Valid laboratories p | 11 | 11 | 11 | 11 |
| Single G_{Cr} (1%) | 2,564 | 2,564 | 2,564 | 2,564 |
| Single G_{Cr} (5%) | 2,355 | 2,355 | 2,355 | 2,355 |
| Single high G_p | 2,320 | 1,181 | 2,213 | 2,417 |
| Single low G_1 | 1,746 | 2,040 | 1,512 | 1,299 |
| Classification (high) | <i>Correct</i> | <i>correct</i> | <i>correct</i> | <i>Straggler</i> |
| Straggler Lab ($G_p > G_{Cr}$ (5%)) | - | - | - | Lab 7 |
| Classification (low) | <i>Correct</i> | <i>correct</i> | <i>correct</i> | <i>correct</i> |
| Outlier Lab ($G_1 > G_{Cr}$ (1%)) | - | - | - | - |
| Double G_{Cr} (1%) | 0,1448 | 0,1448 | 0,1448 | 0,1448 |
| Double G_{Cr} (5%) | 0,2213 | 0,2213 | 0,2213 | 0,2213 |
| Double high $G_{largest}$ | 0,3530 | 0,7224 | 0,3164 | - |
| Double low $G_{smallest}$ | 0,5480 | 0,2748 | 0,5986 | 0,6591 |
| Classification (two largest) | <i>Correct</i> | <i>correct</i> | <i>correct</i> | - |
| Outlier Lab ($G_{largest} < G_{Cr}$ (1%)) | - | - | - | - |
| Classification (two smallest) | <i>Correct</i> | <i>correct</i> | <i>correct</i> | <i>correct</i> |
| Outlier Lab ($G_{smallest} < G_{Cr}$ (1%)) | - | - | - | - |

Single: test for one outlying observation; Double: test for two outlying observations

Sealing quality assessment by mass loss (EN 12373-7)

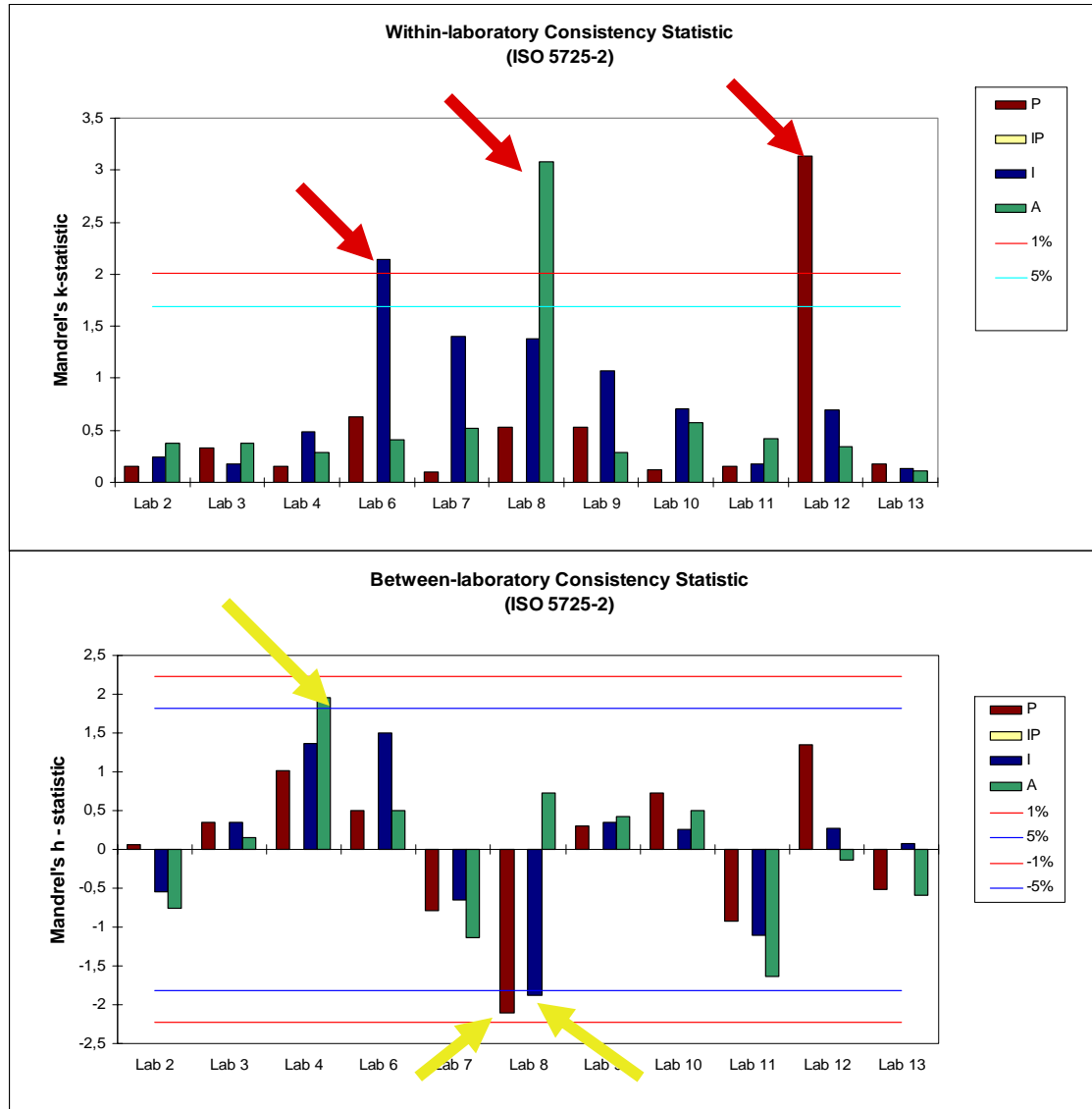


Results of precision analysis

| Level | P | IP | I | A |
|--|--|--------------|--------------|--|
| Number of replicates n | 3 | 3 | 3 | 3 |
| Valid laboratories p | 10 | 11 | 10 | 10 |
| General mean m / g.dm⁻² | 15,92 | 477,5 | 17,86 | 13,19 |
| Repeatability variance s_r^2 | 0,426 | 140,55 | 0,457 | 0,430 |
| Between-lab variance s_L^2 | 8,359 | 141,11 | 9,708 | 7,442 |
| Reproducibility variance s_R^2 | 8,785 | 281,66 | 10,164 | 7,871 |
| Repeatability std. dev. s_r | 0,65 | 11,7 | 0,68 | 0,66 |
| Reproducibility std. dev. s_R | 2,96 | 16,8 | 3,19 | 2,81 |
| Repeatability COV (s_r/m) | 4,1% | 2,5% | 3,8% | 5,0% |
| Reproducibility COV (s_R/m) | 18,6% | 3,5% | 17,9% | 21,3% |
| Number of outliers | 2 | 1 | 1 | 3 |
| Number of excluded outliers | 1 | 0 | 1 | 1 |
| Outlier type | ¹ Mh, ² Mk, ³ C | Mk | Mk, C | ¹ Mh, ² Mk, ³ C |
| Outlier laboratories | Lab 7 ¹ Lab 10 ^{1,2,3} | Lab 9 | Lab 8 | Lab 7 ¹ Lab 8 ^{2,3} |

Outlier type: Mh – Mandel's h ; Mk – Mandel's k ; C - Cochran's; G(I) – Grubs (one outlying observation); G(II) – Grubs (two outlying observations)

Sealing quality assessment by measurement of admittance (EN 12373-5)





Sealing quality assessment by measurement of admittance (EN 12373-5)

Laboratories outside critical value lines of **Mandel's** statistics

| Level | P | IP | I | A |
|------------------------|------------------|------|------------------|------------------|
| <i>Mandel's k-plot</i> | Lab 12 | n.a. | Lab 6 | Lab 8 |
| Classification | <i>Outlier</i> | n.a. | <i>Outlier</i> | <i>Outlier</i> |
| <i>Mandel's h-plot</i> | Lab 8 | n.a. | Lab 8 | Lab 4 |
| Classification | <i>Straggler</i> | n.a. | <i>Straggler</i> | <i>Straggler</i> |

n. a. – not applied

Cochran's test results

| Level | P | IP | I | A |
|------------------------------------|----------------|------|------------------|----------------|
| Valid laboratories p | 11 | n.a. | 11 | 11 |
| Number of replicates n | 3 | n.a. | 3 | 3 |
| 1% Critical value $C_{Cr (1\%)}$ | 0,504 | n.a. | 0,504 | 0,504 |
| 5% Critical value $C_{Cr (5\%)}$ | 0,417 | n.a. | 0,417 | 0,417 |
| Cochran's test statistic C | 0,893 | n.a. | 0,419 | 0,862 |
| Classification | <i>Outlier</i> | n.a. | <i>Straggler</i> | <i>Outlier</i> |
| Outlier Lab ($C > C_{Cr (1\%)}$) | Lab 12 | n.a. | Lab 6 | Lab 8 |

n. a. – not applied



Sealing quality assessment by measurement of admittance (EN 12373-5)

Grubb's test results

| Level | P | IP | I | A |
|--|----------------|------|----------------|----------------|
| Valid laboratories p | 11 | n.a. | 11 | 11 |
| Single G_{Cr} (1%) | 2,564 | n.a. | 2,564 | 2,564 |
| Single G_{Cr} (5%) | 2,355 | n.a. | 2,355 | 2,355 |
| Single high G_p | 1,352 | n.a. | 1,497 | 1,961 |
| Single low G_1 | 2,099 | n.a. | 1,884 | 1,642 |
| Classification (high) | <i>correct</i> | n.a. | <i>correct</i> | <i>correct</i> |
| Outlier Lab ($G_p > G_{Cr}$ (1%)) | - | n.a. | - | - |
| Classification (low) | <i>correct</i> | n.a. | <i>correct</i> | <i>correct</i> |
| Outlier Lab ($G_1 > G_{Cr}$ (1%)) | - | n.a. | - | - |
| Double G_{Cr} (1%) | 0,1448 | n.a. | 0,1448 | 0,1448 |
| Double G_{Cr} (5%) | 0,2213 | n.a. | 0,2213 | 0,2213 |
| Double high $G_{largest}$ | 0,6505 | n.a. | 0,4987 | 0,4826 |
| Double low $G_{smallest}$ | 0,3741 | n.a. | 0,4238 | 0,5148 |
| Classification (two largest) | <i>correct</i> | n.a. | <i>correct</i> | <i>correct</i> |
| Outlier Lab($G_{largest} < G_{Cr}$ (1%)) | - | n.a. | - | - |
| Classification (two smallest) | <i>correct</i> | n.a. | <i>correct</i> | <i>correct</i> |
| Outlier Lab($G_{smallest} < G_{Cr}$ (1%)) | - | n.a. | - | - |

Single: test for one outlying observation; Double: test for two outlying observations
 n. a. – not applied

Sealing quality assessment by measurement of admittance (EN 12373-5)

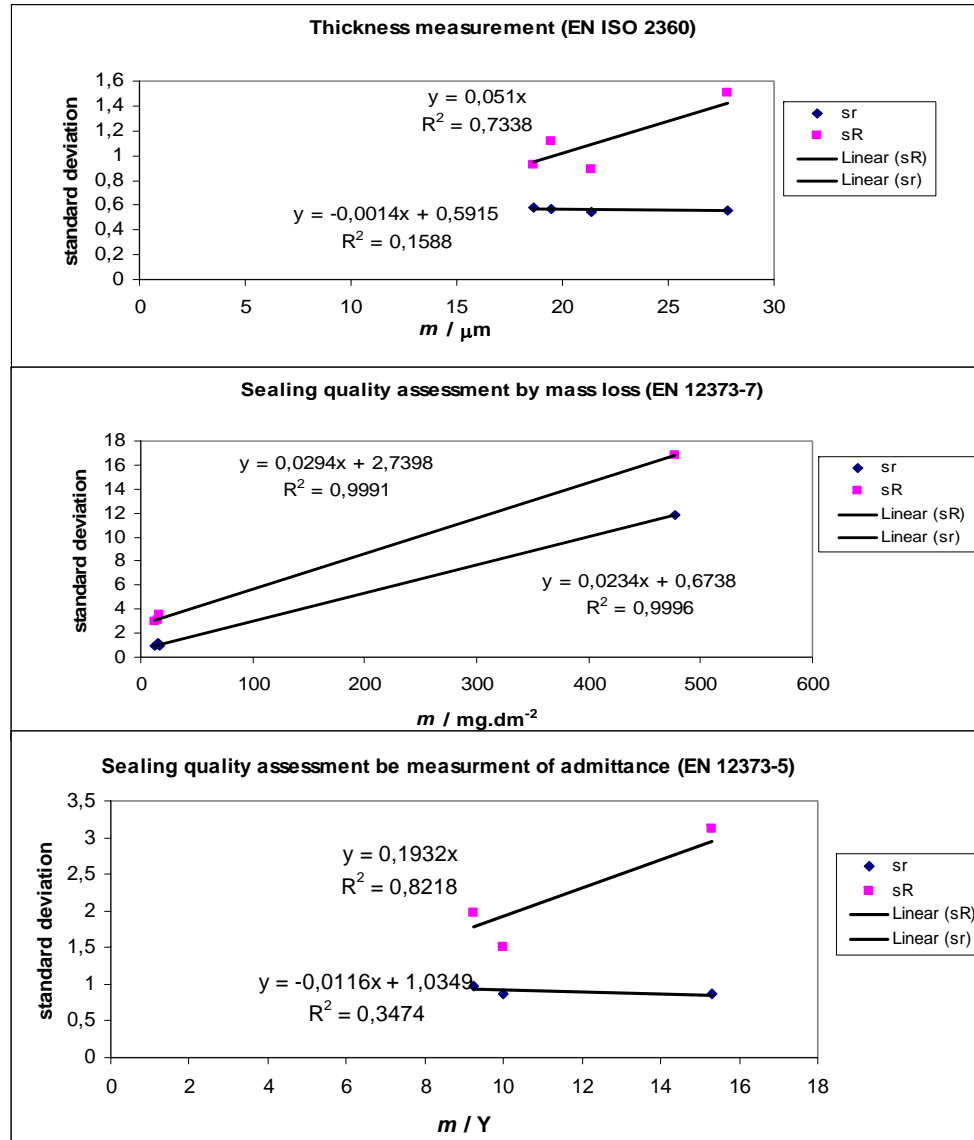


Results of precision analysis

| Level | P | I | A |
|---|--|--------------|-------------|
| Number of replicates n | 3 | 3 | 3 |
| Valid laboratories p | 10 | 11 | 10 |
| General mean m / Y | 8,98 | 15,29 | 9,88 |
| Repeatability variance s_r^2 | 0,113 | 0,747 | 0,113 |
| Between-lab variance s_L^2 | 2,858 | 8,974 | 1,794 |
| Reproducibility variance s_R^2 | 2,970 | 9,720 | 1,907 |
| Repeatability std. dev. s_r | 0,34 | 0,86 | 0,34 |
| Reproducibility std. dev. s_R | 1,72 | 3,12 | 1,38 |
| Repeatability COV (s_r/m) | 3,7% | 5,7% | 3,4% |
| Reproducibility COV (s_R/m) | 19,2% | 20,4% | 14,0% |
| Number of outliers | 2 | 1 | 1 |
| Number of excluded outliers | 1 | 0 | 1 |
| Outlier type | ¹ Mh, ² Mk, ³ C | Mk | Mk, C |
| Outlier laboratories | Lab 8 ¹ Lab 12 ^{2,3} | Lab 6 | Lab 8 |

Outlier type: Mh – Mandel's h ;Mk – Mandel's k ; C - Cochran's ; G(I) – Grubs (one outlying observation) ; G(II) – Grubs (two outlying observations)

Dependency analysis of precision (repeatability and reproducibility) with the mean



Precision analysis results



| EN ISO 2360 – Thickness measurement | Coating type | | | | Excluded data lab:coating type |
|--|---|-------|-------|------|--------------------------------|
| | P | IP | I | A | |
| General mean $m / \mu\text{m}$ | 18,6 | 19,5 | 27,8 | 21,4 | None |
| Repeatability std. dev. s_r | 0,58 | 0,57 | 0,56 | 0,54 | |
| Reproducibility std. dev. s_R | 0,92 | 1,12 | 1,51 | 0,89 | |
| Global repeatability std. dev. | 0,56 | | | | |
| Global reproducibility std. dev. | $S_R = 0,051 m (R^2=0,7338)$ | | | | |
| | | | | | |
| EN 12373-7 - Sealing quality assessment by mass loss | Coating type | | | | Excluded data lab:coating type |
| | P | IP | I | A | |
| General mean $m / \text{g.dm}^{-2}$ | 15,9 | 477,5 | 17,9 | 13,2 | Lab 10:P Lab 8:I Lab 8:A |
| Repeatability std. dev. s_r | 0,65 | 11,9 | 0,68 | 0,66 | |
| Reproducibility std. dev. s_R | 2,96 | 16,8 | 3,19 | 2,81 | |
| Global repeatability std. dev. | $S_R = 0,0234 m + 0,6738 (R^2 \approx 1)$ | | | | |
| Global reproducibility std. dev. | $S_R = 0,0294 m + 2,7398 (R^2 \approx 1)$ | | | | |
| | | | | | |
| EN 12373-5 - Sealing quality assess. by admittance | Coating type | | | | Excluded data lab:coating type |
| | P | IP | I | A | |
| General mean m / Y | 8,98 | n.a | 15,29 | 9,88 | Lab 12:P Lab 8:A |
| Repeatability std. dev. s_r | 0,34 | n.a | 0,86 | 0,34 | |
| Reproducibility std. dev. s_R | 1,72 | n.a | 3,12 | 1,38 | |
| Global repeatability std. dev. | 0,51 | | | | |
| Global reproducibility std. dev. | $S_R = 0,1932 m (R^2=0,8218)$ | | | | |
| | | | | | |

Thickness
 Repeatability=0.56
 Reproducibility=1.51
 (standard :
 1 μm (until 10 μm or 10%)

Sealing/mass loss
 < 30
 Repeatability=1
 Reproducibility=3

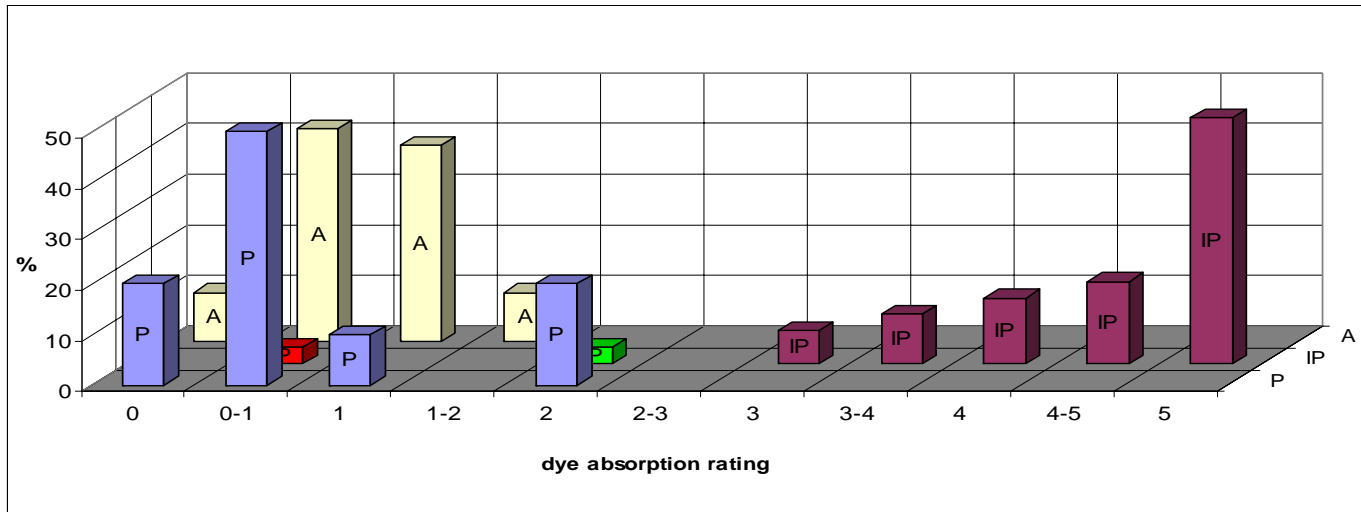
Sealing/admittance
 Repeatability=0.51
 Reproducibility=3.12

Estimation of loss of absorptive power of anodic oxidation coatings after sealing by dye spot test (EN 12373-4)



Analysis of qualitative results

Frequency distribution of the results



| Coating type | Dye absorption rating | | | Laboratory with results outside the range of 95% |
|--------------|-----------------------|-------------------|-------------------------|--|
| | Mode | Median | Range of 95% of results | |
| P | 0-1 | 0-1 | 0 to 2 | None |
| IP | 5 | Between 4-5 and 5 | 3 to 5 | Lab 2 (1 result) |
| A | 0-1 | 0-1 | 0 to 1-2 | None |