

Science For A Better Life

UN ECE - GRSG - IGPG
3rd Meeting
Taber Round Robin Test Analysis

2011-11-21 Dr. Frank Buckel

Agenda

- short summary of the IGPG Taber Round Robin Test outcome as discussed at the 2nd meeting
  - general info re Taber test:
    - precision of the Taber abrasion test according to ASTM
    - ISO discussion about wheel specification
- list of potential sources for the large variation observed in the IGPG Taber Round Robin Test
  - new investigation details on IGPG Taber Round Robin:
    - update on test procedure influence
    - results of the instrument calibration verification
    - evaluation of wheels lots creating “unusual” high values on plastic samples
  - overview of current status regarding potential sources
- summary & conclusion

IGPG - Taber Round Robin Test

results as presented at the 2nd meeting

Taber Round Robin Test information:

- 11 test laboratories participated in the round robin
- 3 different glazing sample types with 3 identical samples for each type were tested with 1000 cycles using CS-10F wheels (on-hand wheels, so different lots were used)
- the test was performed either by using the ECE R43 or the ASTM D 1044 (08) procedure

suitable to check the "as-is" status

	Glass	coated PMMA	coated PC
	Δ haze [%]		
Lowest measured value	0,58	3,46	1,70
Highest measured value	2,00	39,94	40,90
Arithmetic mean of all values	**1,18**	**15,44**	**10,52**
Standard deviation	**0,37**	**10,59**	**13,11**

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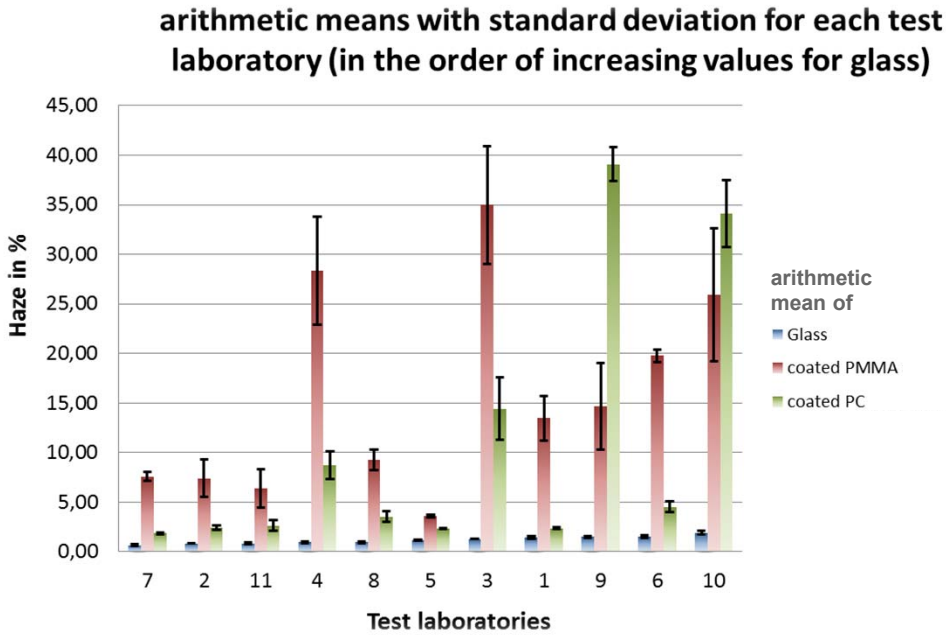
Result from an approval standpoint:

- no issue for glass – since all values do not exceed 2% haze due to abrasion
- for plastic glazing everything including an approval for all (besides windscreen) glazing locations
- strictly spoken no ECE R43 approval is possible anymore since the CS 10F wheels do not fulfill the wheel specification with a hardness of 72 ± 5 IRHD mentioned in ECE R43



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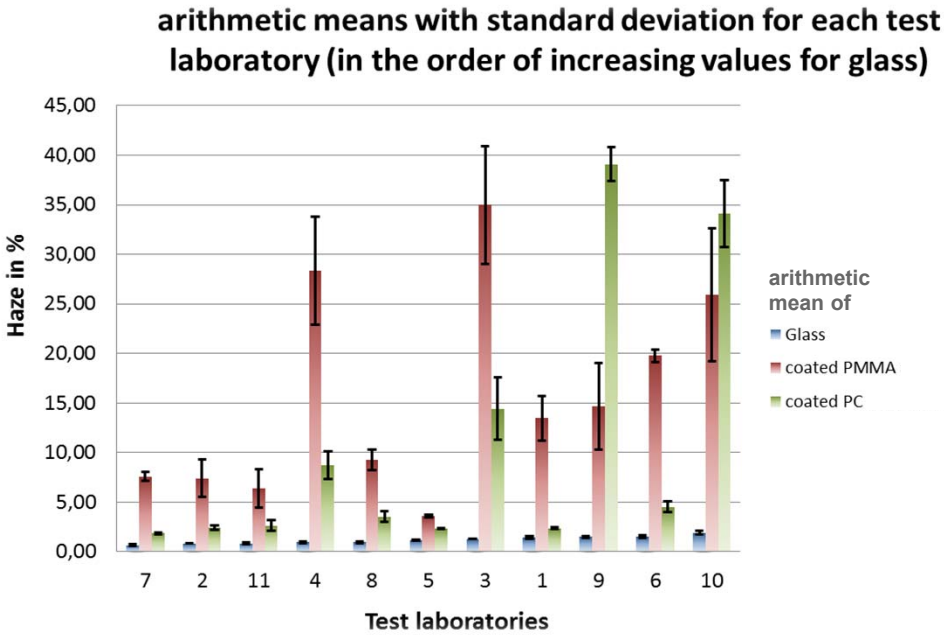
suitable to check the "as-is" status

Result from an approval standpoint:

- glass OK
- plastic "unpredictable"
- wheels do NOT comply with spec mentioned

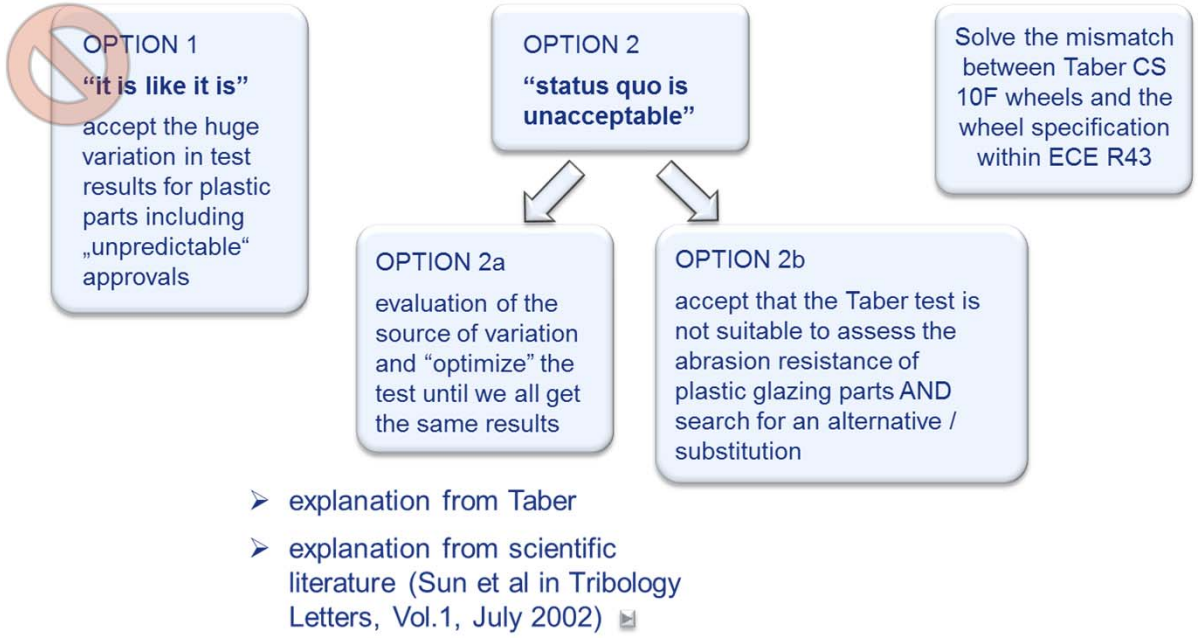


Conclusions

at the 2nd IGPG meeting based on the results

- discussion of the results yielded to double-tracked further action
  - investigation of the sources for variation in the Taber Round Robin test (investigation of “suspicious” wheels; instrument calibration)
  - Round Robin Test with alternative abrasion tests (car wash and sand trickling)

  to be presented at the next meeting

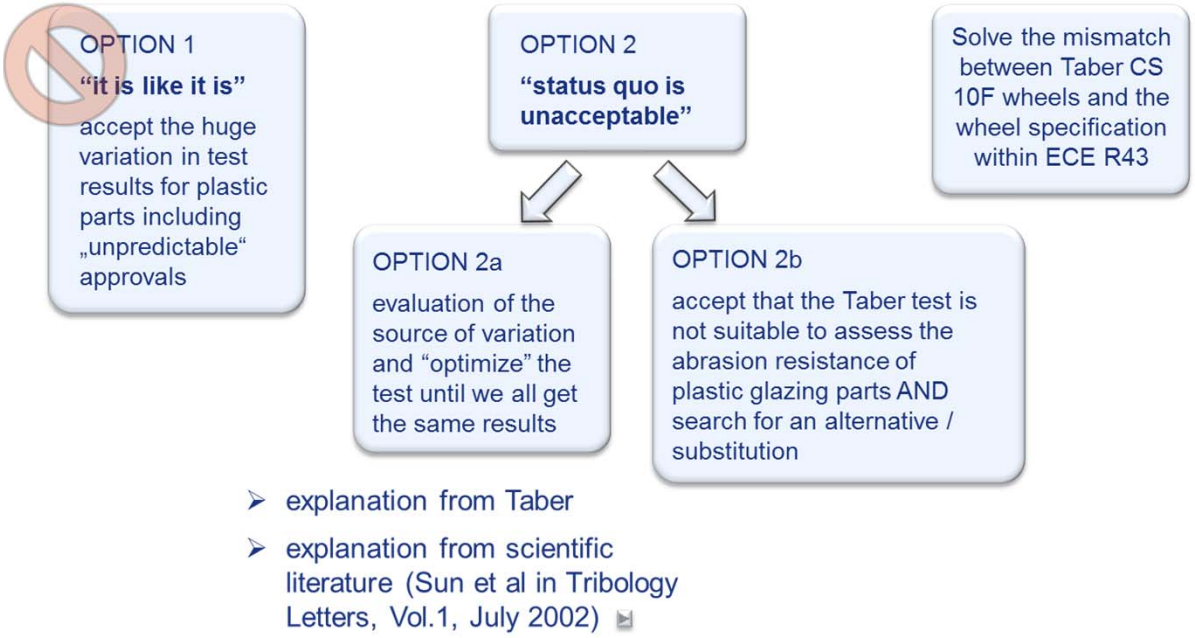


Conclusions

at the 2nd IGPG meeting based on the results

To do:

- evaluating sources of variation
- checking alternative abrasion tests



➢ Question before starting to investigate the sources of variation for testing plastic substrates:

"normal" precision under "optimal" conditions ?

Precision of the Taber test

information in ASTM D1044 (2008)

13. Precision and Bias

13.1 Table 1 is based on a round robin conducted in 2004, involving five materials tested by five laboratories. Each lab made six (6) determinations for each material and cycle combination. It should be noted that the test procedure used for the round robin involved higher reface cycles, and no consideration was given to the useful life of the ST-11 refacing stone.

13.1.1 In Table 1 for the materials indicated:

TABLE 1 Precision Statement Based on Three Replicate Observations

Material	Number of Cycles	Mean	Values in Units of Percent Haze				
			S_x	S_r	S_R	r	R
Glass	1000	0.69	0.19	0.16	0.25	0.45	0.70
Polycarbonate—Coating 1	[illegible]	2.52	0.76	0.95	1.19	2.65	[illegible]
Polycarbonate—Plasma Coating	1000	2.82	0.83	0.93	1.22	2.61	3.42
Polycarbonate—Coating 2	100	8.95	1.23	1.64	1.99	4.58	5.57
Polycarbonate—Coating 3	500	11.65	2.95	4.82	5.48	13.49	15.33

S_r = pooled within-laboratories standard deviation of the mean for three or ten specimens,

S_R = total among-laboratories standard deviation of the mean for three or ten specimens,

$r = 2.83\ S_r$ (see 13.2), and

$R = 2.83\ S_R$ (see 13.3).

Other materials may give somewhat different results.

13.2 *Repeatability*—In comparing two averages for the same material, obtained by the same operator using the same equipment on the same day, the average should be judged not equivalent if they differ by more than the r value for that material and condition.

13.3 *Reproducibility*—In comparing two averages for the same material, obtained by different operators using different equipment, the averages should be judged not equivalent if they differ by more than the R value for that material and condition.

13.4 The judgments in accordance with 13.2 and 13.3 will be correct in approximately 95 % of such comparisons.

13.5 For further information on the methodology used in this section, see Practice E 691.

13.6 *Bias*—No statement is made about bias of this test method, as there is no absolute method available as a referee method.

14. Keywords

14.1 abrasion; haze; hazemeter; surface abrasion; Taber abraser

- **higher standard deviation for the coated plastic substrates** (more than four times higher compared to glass)
- based on test precision (method depended) not on performance (material dependent) the test is **more suited for glass** than for coated plastics

- according to the **reproducibility** statement values for coated polycarbonate and 1000 cycles are identical which do not differ more than 3.42%.
- therefore the **approval hurdle** of below 2% delta haze after 1000 cycles **is far below the precision of the method** for coated polycarbonate with 3.4%
- even the repeatability is with 2,61% above the hurdle

Summary:

Considering this it is not possible with coated polycarbonate to fulfill the approval requirement **not** because of the material performance but because of the precision of the method. This is the difference to glass with a variation of 0.7% for identical results which is below the requirement hurdle of 2%.

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Comment from Taber:

"I agree that the data shows glass is much more consistent than the other materials tested. However, I do not have sufficient experience to know if the variation shown with the polycarbonate is a result of the coating process or the test procedure."

2% approval hurdle **<** **3,4%** precision of method for plastic substrates

Summary:

insufficient precision for plastic substrates

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analysis similar to the precision statement in ASTM

material	number of cycles	average ẍ	standard deviation s_x
Glass	1000	1,1653	0,3839
coated PC	1000	10,5227	13,4669
coated PMMA	1000	15,5691	10,3459

5.6 *Repeatability and Reproducibility*—These terms deal with the variability of test results obtained under specified laboratory conditions. Repeatability concerns the variability between independent test results obtained within a single laboratory in the shortest practical period of time by a single operator with a specific set of test apparatus using test specimens (or test units) taken at random from a single quantity of homogeneous material obtained or prepared for the ILS. Reproducibility deals with the variability between single test results obtained in different laboratories, each of which has applied the test method to test specimens (or test units) taken at random from a single quantity of homogeneous material obtained or prepared for the ILS.

Comparison to ASTM D 1044 (2008):

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analysis similar to the precision statement in ASTM

different operators, instruments and wheel lots

material	number of cycles	average ẍ	standard deviation s_x	repeatability standard deviation s_r	reproducibility standard deviation s_R	repeatability r	reproducibility R
Glass	1000	1,1653	0,3839	0,1011	0,3927	0,28	1,10
coated PC	1000	10,5227	13,4669	1,5813	13,5287	4,43	37,88
coated PMMA	1000	15,5691	10,3459	3,5976	10,7548	10,07	30,11

Comparison to ASTM D 1044 (2008):

different operators, instruments and *probably* same wheel lots

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- Our Round Robin checking the **“as is”-status** has revealed a reproducibility for plastic substrates of more than 30% AND
- the question was is that the **“true” reproducibility** when different wheel lots are used OR are there **further sources of variation** ?

ISO TC22 SC11 committee

abrasive wheel specification in glazing standards

background information:

- ISO 3537 and ISO 15082 are currently **under revision by ISO TC 22 SC11** (road vehicles - safety glazing materials), both describing the Taber abrasion test
- the **proposal to modify the wheel specification** from via surface hardness ("wheels shall have a hardness of 72 IRHD ± 5 IRHD … on the centerline of the abrading surface") to via grade ("grade of wheel designated CS-10F shall be used") is intensively discussed since almost one year

standard / regulation	wheel specification via surface hardness	wheel specification via grade CS-10F
ISO 3537	current version	proposed
ISO 15082	current version	proposed
ASTM D 1044	-	current version
ECE R43	current version	-

reasons for *changing* the specification:

- **CS-10F wheels** from Taber **no longer fulfill** the surface hardness requirement
- surface hardness alone does **not fully specify the abrasiveness of the wheels** (abrasive particles (kind, amount, size and shape) are more important)

reasons for *keeping* the specification:

- standards in general should mention a **specification and not a product name**
- in Japan so-called **Daiwa C180 0XF wheels** are used, which give abrasion results similar to "old" CS-10F (gen. I) wheels and still fulfill the current hardness specification

status:

- a Round Robin test is underway in order to compare results gained with the two different wheels (but this Round Robin will be performed with **ONLY ONE TABER WHEEL LOT**)

ISO TC22 SC11 committee

abrasive wheel specification in glazing standards

CS 10F from Taber	**C180 0XF** from Daiwa
customary wheels	so far only used in Japan
do not comply with surface hardness spec.	surface hardness spec. ok

standard / regulation	wheel specification via surface hardness	wheel specification via grade CS-10F
ISO 3537	current version	proposed
ISO 15082	current version	proposed
ASTM D 1044	-	current version
ECE R43	current version	-

status: Round Robin running with *one wheel lot* from Taber and one from Daiwa

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update on investigation of sources for large variation

Possible reasons for high standard deviation when testing plastics:

- **different test procedure used**
  - two procedures are used (only ASTM D1044 is updated since generation IV wheels are used)
  - review of according to Taber crucial differences
- **calibration and age of the instrument (including suction force)**
  - results of the calibration verification using a special kit from Taber
- **consistency of CS-10F wheels**
  - results of Taber´s inspection of two used wheels lots
  - additional investigation from lab no. 9/10

✓ **haze measurement**
  - haze cross check for PC samples done by PC sample manufacturer confirm that there is no significant deviation in haze measurement between the participating test labs

✓ **sample inhomogeneity**
  - since the repeatability is good compared to the reproducibility the samples are not the source

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update on test procedure influence

crucial items of the test procedure			
refacing medium (ST-11 stone)	vacuum nozzle orifice size (11 mm)	vacuum nozzle gap (0,8-1,6 mm)	use of a brush after refacing

Info from Taber:
Before testing, the abrasive wheels must be **resurfaced with the ST-11 refacing stone to ensure a consistent abrading action** (without, it is possible to transfer debris from previous test and / or clog the running surface of the wheels; using S-11 refacing disc will typically result in a higher haze on plastic specimens).

Info from Taber:
The standard diameter of the vacuum nozzle is 8mm. Prior to the release of the Taber CS-10F Type IV wheels, validation testing indicated increased wear on the outer edges of the of the wear path. It was determined the 8mm openings were not effective at removing wear debris from across the entire wear path and three-body abrasion was being generated. The **11mm openings were found to significantly improve wear debris removal** when combined with a vacuum suction of 100.

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update on test procedure influence

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refacing medium (ST-11 stone)	vacuum nozzle orifice size (11 mm)	vacuum nozzle gap (0,8-1,6 mm)	use of a brush after refacing

Info from Taber:
Furthermore, to effectively remove the wear debris it is necessary to have a vacuum nozzle gap (distance from the specimen to the vacuum nozzle) of 0,8 to 1,6 mm. A larger vacuum nozzle gap lead to significantly increased haze values.

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update on test procedure influence

crucial items of the test procedure			
refacing medium (ST-11 stone)	vacuum nozzle orifice size (11 mm)	vacuum nozzle gap (0,8-1,6 mm)	use of a brush after refacing

huge effect — small effect

Info from Taber:
The old refacing procedure referenced in Section 9 of ASTM D1044-05 may leave loose abrasive grit particles on the wheel surface. Taber has investigated and concluded that three-body abrasion is occurring until the debris is removed. For certain materials, there does not appear to be much impact on the test results. However with others, this loose debris can **increase the change in haze by approximately 1.0%**. Therefore now the use of a antistatic brush is recommended.

ASTM D 1044 from 2005

9.2 Before abrading each specimen, reface the wheels for 25 cycles on the fine side of the ST-11 refacing stone. (**Warning**—Do not brush or touch the running surface of the wheels after they are refaced. New wheels or wheels trued using a diamond tool refacer, must first be broken in with 100

ASTM D 1044 from 2008

9.2 Before abrading each specimen, reface the wheels for 25 cycles on the fine side of the ST-11 refacing stone. After refacing, use a soft bristle, anti-static brush to lightly brush the wheel surfaces to remove any loose particulate matter before abrading a specimen. (**Warning**—Do not touch the running surface of the wheels after they are refaced. New wheels or

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update on test procedure influence

no. of the test lab	serial no. of the instrument	lot no. CS 10F wheels	values after 1000 cycles on coated PC	values after 1000 cycles on coated PMMA	crucial items of the test procedure			
					refacing medium (ST-11 stone)	vacuum nozzle orifice size (11 mm)	vacuum nozzle gap (0,8-1,6 mm)	use of a brush after refacing
1	968627	DW23D2	2,3%	13,5%	✓	✓	0,8mm ✓	yes ✓
2	894601	EE12D2	2,4%	7,4%	✓	✓	1,0mm ✓	yes ✓
3	20001106	***DD17D2***	14,4%	35,0%	✓	✓	1,1mm ✓	yes ✓
4	904928	DD15D3	8,7%	28,3%	✓	8mm	1,0mm ✓	yes ✓
5	791463	DW22D2	2,3%	3,5%	✓	✓	1,0mm ✓	no
6	20081633	DD15D3	4,5%	19,8%	✓	✓	0,95mm ✓	no
7	904865	EH19D2	1,8%	7,6%	✓	✓	1,0mm ✓	no
8	955822-8	DS04D1	3,5%	9,3%	✓	✓	0,8mm ✓	no
9	771189	DY22D2	39,1%	14,7%	✓	✓	1,6mm ✓	no
10			34,1%	25,9%		8mm	0,8mm ✓	no
11	71000	DW22D2	2,6%	6,4%	✓	✓	1,2mm ✓	no

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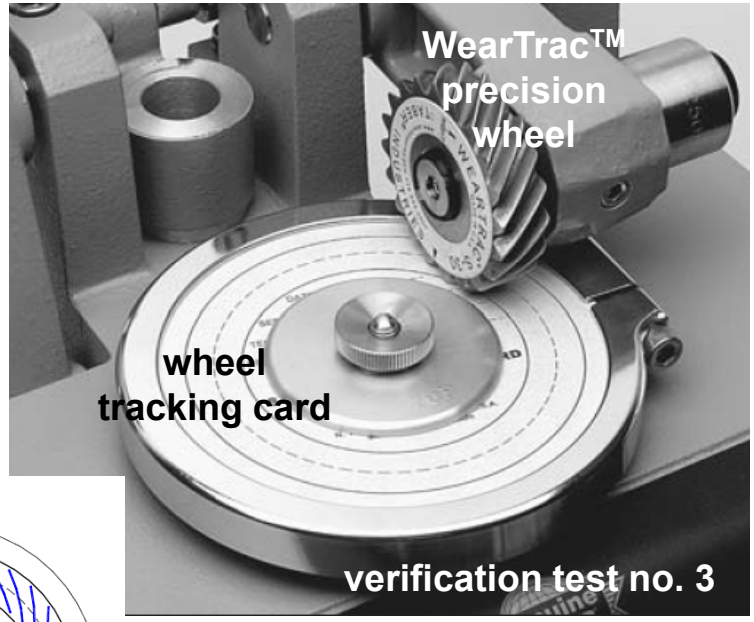
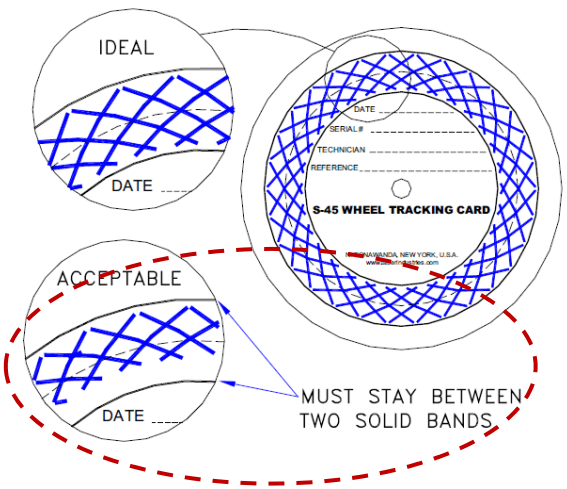
instrument calibration verification – introduction (*source: Taber*)

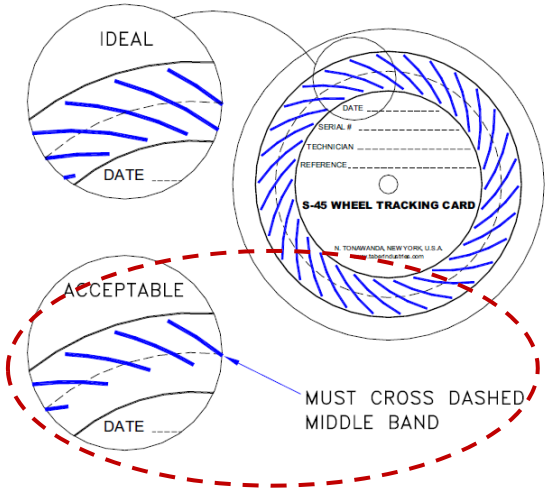
Verification tests:

to check (i) abraser arm alignment, (ii) wheel track and (iii) bearing wear (each could lead to different contact areas of the two wheels with different pressure and therefore abrasion performance on the sample if not within certain limits)

- **test no. 1 (both arms, 1000g load, 1 cycle)**
- **test no. 2 (left arm only, 500g load, 15 cycle)**
- **test no. 3 (right arm only, 500g load, 15 cycle)**







left side:
pass / fail criteria for test no. 1 (both wheels)

right side:
pass / fail criteria for test no. 2&3 (one wheel)

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instrument calibration verification – introduction (*source: Taber*)

Vacuum system evaluation test:

to check vacuum suction force (which could change the type of wear from 2-body to 3-body if debris generated during wear test is not sufficiently removed)

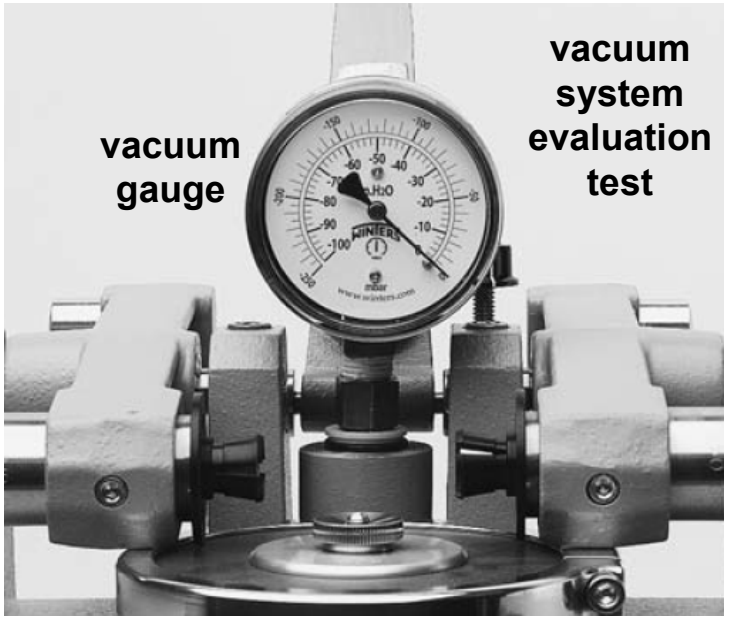
vacuum test pass / fail criteria:

not < 55 inch of water column (137mbar) at a setting of 100

Inspection tests:

to check further influencing parameters

- **test no. 1 vacuum pick-up nozzle port wear inspection for flatness** (visible inspection)
- **test no. 2 table flatness** (no visible wobble; measuring equipment not included in the kit)
- **test no. 3 turntable speed** (rotate at a fixed and constant speed; measuring equipment not included in the kit)
- **test no. 4 accessory weight** (±1g)



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instrument calibration verification – results

no. of the test lab	serial no. of the instrument	verification tests			vacuum system (inches of water column)	inspection tests			
		no. 1 (both arms)	no. 2 (left arm)	no. 3 (right arm)		no. 1 (vacuum nozzle)	no. 2 (table flatness)	no. 3 (table speed)	no. 4 (weight)
1	968627	√	√	√	67	√	√	√	√
2	894601	√	√	√	68	√	*	*	√
3	20001106	√	√	√	61	√	√	√	√
4	904928	√	√	√	65	√	√	√	√
5	791463	√	√	√	62	√	√	√	√
6	20081633	√	√	√	61	√	√	√	√
7	904865	√	√	√	72	√	√	√	√
8	955822-8	√	√	√	68	√	√	√	√
9 & 10	771189	√	√	√	60	√	√	√	√
11	71000	√	√	√	55	√	√	√	√

* not verified because equipment not included in the kit

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instrument calibration verification – results

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8	955822-8	√	√	√	68	√	√	√	√
9 & 10	771189	√	√	√	60	√	√	√	√
11	71000	√	√	√	55	√	√	√	√

* not verified because equipment not included in the kit

IGPG Taber Robin Calibration

Taber Comments Results of Calibrati

All used instruments are within calibration (some are “only” acceptable (not ideal) and Taber has given some recommendations in these cases) and the vacuum suction force is in all cases sufficient.

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evaluation of “high value” wheel lots

	participating lab no. 3	participating lab no. 9/10
CS 10F wheel lot.	DD17D2 (exp. Feb. 2012)	DY22D2 (exp. Nov. 2012)
result of wheel evaluation done by Taber	**not ok**	ok
reason for unusual high values according to Taber	left hand wheel	**?**

Details from Taber´s report: “…wheel set has an anomaly…” (foreign debris or “clumped together” aluminum oxide grain particles embedded in the binder material) “… that is likely responsible for higher than expected abrasion values.”

Question: Why was this issue not observed during pre-delivery inspection?

Answer from Taber: “…it is more likely this anomaly was below the surface of the wheel. Therefore, it would not have been visible during inspection which is why it would have been missed and not found until the wheel began to wear away.”

Comment: This is critical since there is no possibility for a receiving inspection (no spec describing abrasiveness) besides getting “unusual” values

IGPG - Taber Round Robin Test

evaluation of “high value” wheel lots

	participating lab no. 3	participating lab no. 9/10
CS 10F wheel lot.	DD17D2 (exp. Feb. 2012)	DY22D2 (exp. Nov. 2012)
result of wheel evaluation done by Taber	**not ok**	ok
reason for unusual high values according to Taber	left hand wheel	**?**

- wheels passed Taber´s internal spec. ✓
- calibration verification passed ✓
- vacuum nozzle gap in between Taber´s recommendation ✓
- instrument set-up and procedure checked ✓

Taber´s comment: “…not able to explain the extremely high readings for lab 9´s PC …”

“Lab 10 results are not comparable due to different vacuum nozzle opening (8mm).”

Details from Taber´s report: “…wheel set has an anomaly…” (foreign debris or “clumped together” aluminum oxide grain particles embedded in the binder material) “… that is likely responsible for higher than expected abrasion values.”

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further investigations of lab no. 9/10

Round Robin test or new tests result	serial no. of the instrument	lot no. CS 10F wheels	test procedure			PC samples used	values after 1000 cycles on coated PC
			refacing medium (ST-11 stone)	vacuum nozzle orifice size (11 mm)	vacuum nozzle gap (0,8-1,6 mm)		
RR	771189	DY22D2	√	√	1,6mm √	CAP 3214-A	39,1%
new	771189	DW22D2	√	√	0,8mm √	CAP 3214-A	1,2%
new	771189	DW22D2	√	√	1,6mm √	CAP 3214-A	8,2%
new	771189	DW22D2	√	√	3,2mm	CAP 3214-A	32,2%
new	771189	DW22D2	√	√	6,4mm	CAP 3214-A	39,1%

- The vacuum nozzle gap has a tremendous influence (despite the fact that it is not mentioned in ECE R43) even within the range recommended by Taber and ASTM D 1044 from 2008.

> 10.4 Select the load to be used and affix it to the abraser. Lower the vacuum pick-up nozzle and adjust the height to within 0.8 to 1.6 mm [1/32 to 1/16 in.] of the specimen surface.
> from ASTM D 1044 (2008)

- Also changing the wheel lot with apart from that no change can led to dramatically different results on plastic substrates (8,2% vs. 39,1%) and turns a spotlight onto the lot to lot consistency of the wheels.

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update on investigation of sources for large variation

Investigation of possible reasons for high standard deviation testing plastics:

issue not proven but solvable

! **different test procedure used**
- two procedures are used (only ASTM D1044 is updated since gen. IV wheels are used)
- differences which are crucial according to Taber have been checked

➢ results from labs (*no. 4, no. 10*) using a 8 mm vacuum nozzle opening are not comparable according to Taber

✓ **calibration and age of the instrument (including suction force)**
- has been tested using a calibration verification kit (all test labs passed!)

! **consistency of the CS-10F wheels**
- two wheel lots generating high values for plastic substrates have been tested by Taber (one lot was the source for high values, the other lot was ok)

how to prove consistency of wheels?

➢ lab *no. 3* results should be discarded due to issue with DD17D2 wheels used

✓ **haze measurement**

✓ **sample inhomogeneity**

IGPG - Taber Round Robin Test

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material	average $\ddot{x}$	standard deviation s_x	repeat-ability r	repro-ducibility R
coated PC (all labs)	10,5227	13,4669	4,43	37,88
coated PC (without 3,4 and 10)	7,3167	12,8571	1,96	36,04
coated PMMA (all labs)	15,5691	10,3459	10,07	30,11
coated PMMA (without 3,4 and 10)	10,2504	5,2983	5,66	15,54

IGPG - Taber Round Robin Test

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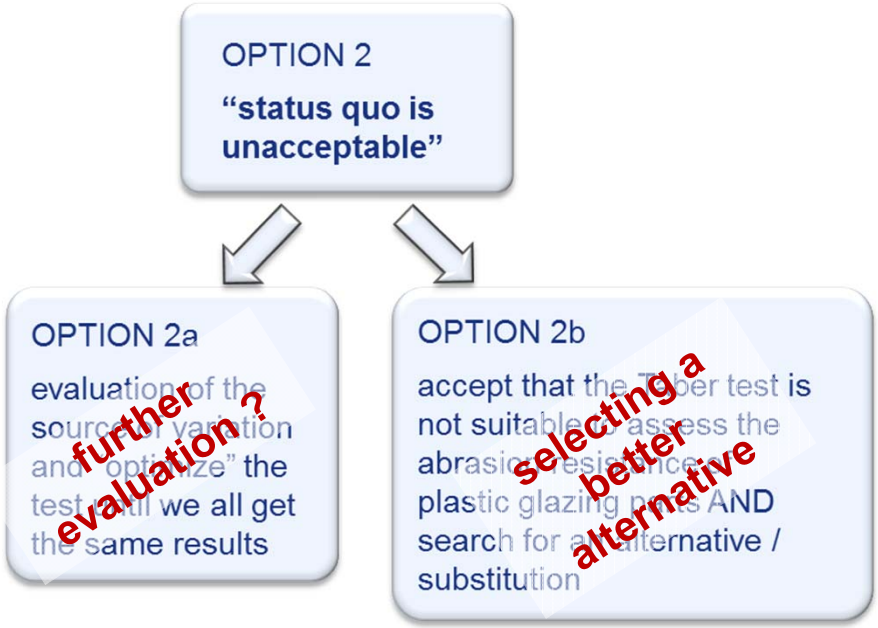
even after discarding labs due to assumed issues the **reproducibility** of the test remains poor

Summary

- All used test instruments passed the **calibration** verification and showed sufficient **vacuum suction force**.
- One source for **“unusual” high values** on plastic substrate was an out-of spec (Taber internal spec) wheel (lot DD17D2).
- The other wheels (lot DY22D) that yielded **“unusual” high values** are according to Taber´s investigation ok, but lead on the same instrument using the same procedure and the same samples to completely different results compared to wheels with the lot DW22D2.
- Even after discarding the results of 3 test labs due to the use of non consistent wheel lot DD17D2 and the use of a different vacuum nozzle openings (8mm) the test precision **remains extremely poor.**



Conclusion

The aim …

… can not be reached by using …

…Taber rotary platform abrasion!

assessment of application related (normal traffic) wear performance on a finished plastic glazing part!

a method testing unrealistic wear on a reference sample with a precision so low that the reproducibility is high above the absolute approval hurdle

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Thank you!

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