


**Finalisation of Impact and Assessment  
Conditions for Inverse Certification Test**

10<sup>th</sup> Meeting of the GRSP Flex PLI Technical Evaluation Group  
Bergisch Gladbach, December 1<sup>st</sup> – 2<sup>nd</sup>, 2009

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Bundesanstalt für Straßenwesen  
(Federal Highway Research Institute)

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## Inverse certification test description

Test parameters

Impact parameter tolerances

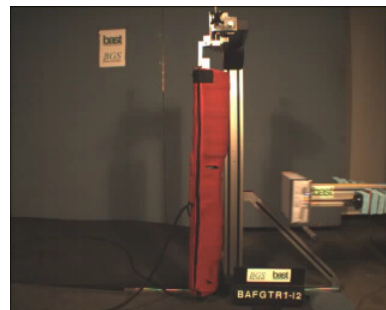
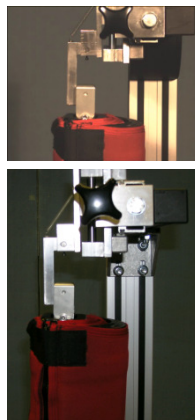
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Summary

## Dynamic full assembly certification test **best**

- Flex PLI (with flesh and skin) is impacted by the upper edge of a linearly guided Al honeycomb impactor at a previously defined impact speed
- Impact location: upper edge of the honeycomb in line with center of knee
- Measurement items – pass/fail parameters:  
three string potentiometers (ACL, PCL, MCL), four strain gauges (tibia moments)



## Dynamic full assembly certification test **bast**

- Test procedure:

**8.2.3.4.1** *The fully assembled FlexPLI (with flesh and skin) shall be stationary suspended vertically from a test rig as shown in Figure 37. It is then impacted by the upper edge of a linearly guided Al honeycomb impactor , covered by a thin paper cloth, at an impact speed of  $11,1 \pm 0,2$  m/s. The legform is to be released from the test rig within 5 ms after the time of first contact to ensure a free flight condition.*

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## Test parameters



- Test parameters:
  - Nominal impact speed = 40 km/h
  - Mass of honeycomb impactor = 8,1 kg
  - Impact height: upper honeycomb edge in line with center of knee
- Test frequency (as agreed at the 9th meeting of Flex-TEG):
  - Previous to each homologation test series
  - After every 30 tests

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## Impact parameter tolerances



- Temperature corridor:

**8.2.3.2.1** *The test facility used for the certification test shall have a stabilised temperature of  $20\pm 2$  °C during certification.*

- Impact velocity corridor:

**8.2.3.4.1** *[...] It is then impacted by the upper edge of a linearly guided Al honeycomb impactor at an impact speed of  $11,1\pm 0,2$  m/s. [...]*

- Impact height corridor:

**8.2.3.4.3** *The upper edge of the honeycomb face is to be in line with the rigid plate of the linearly guided impactor. At time of first contact, the upper edge of the honeycomb is to be in line with the knee joint centre line within a vertical tolerance of  $0\pm 2$  mm.*

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## Impact parameter tolerances



- Pitch / roll / yaw angle corridor:

**8.2.3.4.4** *The FlexPLI pitch angle and therefore the pitch angle of the velocity vector of the honeycomb impactor (rotation around y-axis) at the time of first contact shall be within a tolerance of  $0\pm 2^\circ$  in relation to the lateral vertical plane. The FlexPLI roll angle and therefore the roll angle of the honeycomb impactor (rotation around x-axis) at the time of first contact shall be within a tolerance of  $0\pm 2^\circ$  in relation to the longitudinal vertical plane. The FlexPLI yaw angle and therefore the yaw angle of the velocity vector of the honeycomb impactor (rotation around z-axis) at the time of first contact shall be within a tolerance of  $0\pm 2^\circ$ , to ensure a correct operation of the knee joint.*

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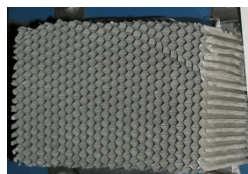
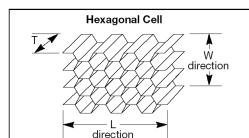
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**Selection of honeycomb material**

- Comparison of honeycomb material

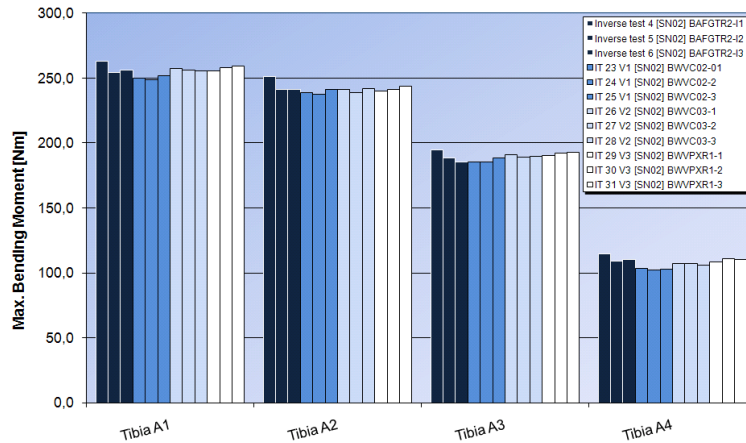
Specification	#1 („Standard“)	#2 (Altern. 1)	#3 (Altern. 2)
Cell size	3/16	1/4	3/16
Alloy	5052	5052	5052
Foil gauge	.001		
Density	3.1	2.3	2.0
Crush strength	75 PSI (-0%/+10%)	75 PSI (-0%/+10%)	75 PSI (±10%)
Dimensions (L*W*T)	200*160*60	200*160*60	200*160*60



## Selection of honeycomb material



- Comparison of honeycomb material – Test results (SN02, three tests each) (compared to the original three SN02 baseline tests)



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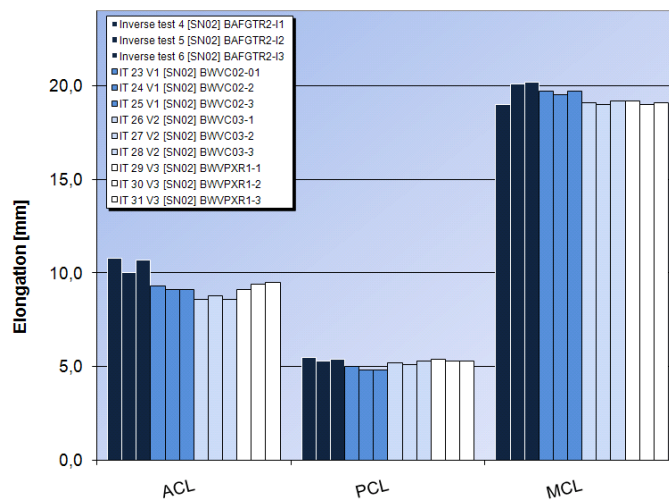
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## Selection of honeycomb material



- Comparison of honeycomb material – Test results (SN02, three tests each)



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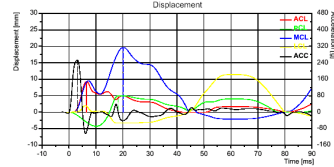
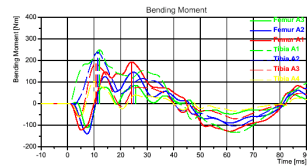
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## Selection of honeycomb material

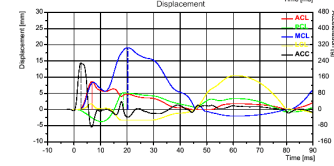
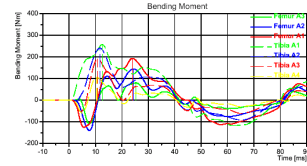


### • Comparison of honeycomb material – Traces:

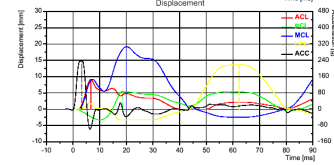
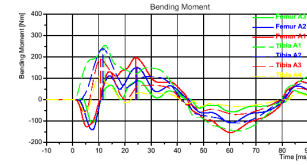
„Standard“



Alternative 1



Alternative 2



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## Selection of honeycomb material



### • Comparison of honeycomb material – Repeatability

Segment	Tibia A1	Tibia A2	Tibia A3	Tibia A4
CV [%] - Original Tests SN02	1,76	2,42	2,63	2,59
CV [%] - „Standard“ SN02	0,60	0,75	0,87	0,59
CV [%] - Alternative 1 SN02	0,38	0,67	0,52	0,65
CV [%] - Alternative 2 SN02	0,79	0,78	0,74	1,29

Segment	ACL	PCL	MCL
CV [%] - Original Tests SN02	4,15	1,85	3,37
CV [%] - „Standard“ SN02	1,26	2,37	0,59
CV [%] - Alternative 1 SN02	1,33	1,92	0,52
CV [%] - Alternative 2 SN02	2,23	1,08	0,52

- Peak tibia and ligament loadings and traces of all test setups with high repeatability
- „Standard“ as well as both alternative materials appropriate for the use within inverse certification test

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## Selection of honeycomb material



Honeycomb material:

**8.2.3.4.2** *The honeycomb of 5052 alloy, which is attached in front of the moving ram, shall have a crush strength of 75 ( $\pm 10\%$ ) psi and dimensions of  $l=200\pm 2$  mm,  $w=160\pm 2$  mm and  $d=60\pm 5$  mm. To ensure a consistent and good level of repeatability, the honeycomb should either have a 3/16 cell size in combination with a density of 3.1 or a 1/4 cell size in combination with a density of 2.3 or a 3/16 cell size in combination with a density of 2.0.*

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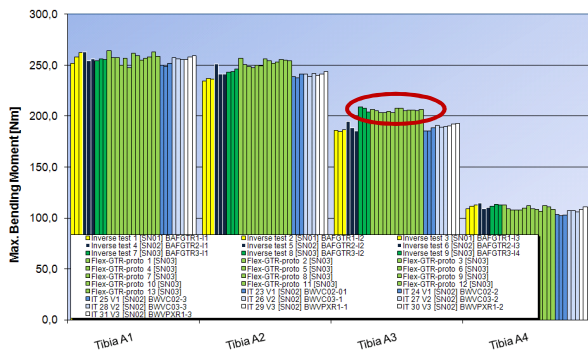
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## Finalisation of certification corridors



- Dataset of TEG-xxx (presented at 9th TEG meeting) has been amended by the results of nine inverse certification tests with SN02 and three different honeycomb types carried out at BAST in November 2009 → 7 setups in total
- Re-calibration of Tibia A3 of SN03 confirmed a defect of the used strain gauge; therefore, only SN01 and SN02 results will be taken into account for the definition of the A3 corridor



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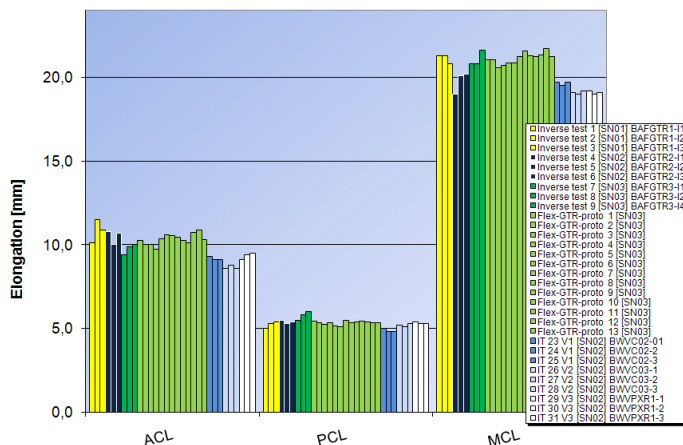
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## Finalisation of certification corridors



- Dataset of TEG-xxx (presented at 9th TEG meeting) has been amended by the results of nine inverse certification tests with SN02 and three different honeycomb types carried out at BAST in November 2009 → 7 setups in total



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## Finalisation of certification corridors



### Coefficients of variation

(31 inverse test results, thereof seven setups with SN01 SN02 SN03, using three different honeycomb types)

Segment	Tibia A1	Tibia A2	Tibia A3	Tibia A4	Remarks / Purpose
Setup 1 - SN01 - "Standard"	2,08	0,51	0,52	1,79	r&R
Setup 2 - SN02 - "Standard"	1,76	2,42	2,63	2,59	r&R, Durability
Setup 3 - SN03 - "Standard"	0,34	0,56	1,27	0,93	r&R, Lab-to-Lab variability
Setup 4 - SN03 - "Standard" (Lab 2)	1,81	1,24	0,75	1,79	Lab-to-Lab variability
Setup 5 - SN02 - "Standard"	0,60	0,75	0,67	0,59	Durability, Honeycomb
Setup 6 - SN02 - Alternative 1	0,38	0,67	0,52	0,65	Honeycomb
Setup 7 - SN02 - Alternative 2	0,79	0,78	0,74	1,29	Honeycomb

Segment	ACL	PCL	MCL	Remarks / Purpose
Setup 1 - SN01 - "Standard"	6,75	3,98	1,37	r&R
Setup 2 - SN02 - "Standard"	4,15	1,85	3,37	r&R, Durability
Setup 3 - SN03 - "Standard"	3,29	4,36	2,19	r&R, Lab-to-Lab variability
Setup 4 - SN03 - "Standard" (Lab 2)	3,05	2,13	1,55	Lab-to-Lab variability
Setup 5 - SN02 - "Standard"	1,26	2,37	0,59	Durability, Honeycomb
Setup 6 - SN02 - Alternative 1	1,33	1,92	0,52	Honeycomb
Setup 7 - SN02 - Alternative 2	2,23	1,08	0,52	Honeycomb

Most segments with good repeatability (CV < 5%)

Only three segments could not be used for the definition of the reproducibility corridor, thereof only one for repeatability reasons

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## Finalisation of certification corridors



### Definition of reproducibility corridor

(Setups and segments with repeatable test results [CV < 5%]):

Segment	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
Setups for Reproducibility Corridor [CV < 5%]	1-7	1-7	1-2, 5-7	1-7	2-7	1-7	1-7
Pooled Mean with CV < 5%	255,87	242,53	188,67	109,20	9,63	5,31	20,13
Upper Limit	281,46	266,78	207,54	120,12	10,59	5,84	22,15
Lower Limit	230,28	218,27	169,81	98,28	8,66	4,77	18,12

### Determination of setups and segments with reproducible test results:

Setup / Segment	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
Setup 1 - SN01 - "Standard" - MAX	262,00	236,60	186,80	112,70	11,50	5,40	21,30
Setup 1 - SN01 - "Standard" - MIN	251,40	234,30	184,90	108,90	10,10	5,00	20,80
Setup 2 - SN02 - "Standard" - MAX	262,70	251,30	194,90	114,50	10,80	5,50	20,20
Setup 2 - SN02 - "Standard" - MIN	254,00	240,90	185,10	108,90	10,00	5,30	19,00
Setup 3 - SN03 - "Standard" - MAX	255,80	245,80	209,00	113,60	10,00	6,00	21,60
Setup 3 - SN03 - "Standard" - MIN	254,20	243,20	204,00	111,50	9,40	5,50	20,80
Setup 4 - SN03 - "Standard" (Lab 2) - MAX	264,34	256,37	207,87	112,55	10,88	5,49	21,71
Setup 4 - SN03 - "Standard" (Lab 2) - MIN	248,50	237,50	185,50	102,40	8,60	4,80	19,00
Setup 5 - SN02 - "Standard" - MAX	251,50	241,00	188,30	103,60	9,30	5,00	19,70
Setup 5 - SN02 - "Standard" - MIN	248,50	237,50	185,50	102,40	9,10	4,80	19,50
Setup 6 - SN02 - Alternative 1 - MAX	257,50	241,50	190,90	107,30	8,80	5,30	19,20
Setup 6 - SN02 - Alternative 1 - MIN	255,60	238,50	189,00	106,10	8,60	5,10	19,00
Setup 7 - SN02 - Alternative 2 - MAX	259,30	243,70	193,00	110,90	9,50	5,40	19,20
Setup 7 - SN02 - Alternative 2 - MIN	255,30	240,10	190,20	108,30	9,10	5,30	19,00
Reproducible test results (Setups and segments within Reproducibility Corridor)	1-7	1-7	1-2, 5-7	1-7	3, 5, 7	1-2, 4-7	1-7

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## Finalisation of certification corridors



### Definition of certification corridor

(Setups and segments with reproducible test results):

Setup / Segment	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
Setup 1 - SN01 - "Standard" - MAX	262,00	236,60	186,80	112,70	10,00	5,40	21,30
Setup 1 - SN01 - "Standard" - MIN	251,40	234,30	184,90	108,90		5,00	20,80
Setup 2 - SN02 - "Standard" - MAX	262,70	251,30	194,90	114,50	10,00	5,50	20,20
Setup 2 - SN02 - "Standard" - MIN	254,00	240,90	185,10	108,90		5,30	19,00
Setup 3 - SN03 - "Standard" - MAX	255,80	245,80	185,10	113,60	10,00	5,00	21,60
Setup 3 - SN03 - "Standard" - MIN	254,20	243,20		111,50	9,40		20,80
Setup 4 - SN03 - "Standard" (Lab 2) - MAX	264,34	256,37	185,10	112,55	10,00	5,49	21,71
Setup 4 - SN03 - "Standard" (Lab 2) - MIN	248,50	237,50		102,40		4,80	19,00
Setup 5 - SN02 - "Standard" - MAX	251,50	241,00	188,30	103,60	9,30	5,00	19,70
Setup 5 - SN02 - "Standard" - MIN	248,50	237,50	185,50	102,40	9,10	4,80	19,50
Setup 6 - SN02 - Alternative 1 - MAX	257,50	241,50	190,90	107,30	10,00	5,30	19,20
Setup 6 - SN02 - Alternative 1 - MIN	255,60	238,50	189,00	106,10		5,10	19,00
Setup 7 - SN02 - Alternative 2 - MAX	259,30	243,70	193,00	110,90	9,50	5,40	19,20
Setup 7 - SN02 - Alternative 2 - MIN	255,30	240,10	190,20	108,30	9,10	5,30	19,00
<b>Maximum</b>	264,34	256,37	194,90	114,50	10,00	5,50	21,71
<b>Minimum</b>	248,50	234,30	184,90	102,40	9,10	4,80	19,00
Max * 1,05 (Consideration of scatter)	277,56	269,19	204,65	120,23	10,50	5,78	22,80
Min * 0,95 (Consideration of scatter)	236,08	222,59	175,66	97,28	8,65	4,56	18,05
<b>Certification Corridor Upper Limit</b>	277	269	204	120	10,5	6	23
<b>Certification Corridor Lower Limit</b>	237	223	176	98	8,5	4,5	18

Calculated values have been rounded in a way such that the corridor is kept tight.

For feasibility reasons, the corridor for ACL and PCL has been widened.

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## Finalisation of certification corridors



### Verification of certification corridor (Application to 31 Flex-GTR tests):

Test #	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
BAFGTR1-11							
BAFGTR1-12							
BAFGTR1-13							
BAFGTR2-11							
BAFGTR2-12							
BAFGTR2-13							
BAFGTR3-11							
BAFGTR3-12							
BAFGTR3-13							
BAFGTR3-14							
Flex-GTR-protot 1 [SN03]							
Flex-GTR-protot 2 [SN03]							
Flex-GTR-protot 3 [SN03]							
Flex-GTR-protot 4 [SN03]							
Flex-GTR-protot 5 [SN03]							
Flex-GTR-protot 6 [SN03]							
Flex-GTR-protot 7 [SN03]							
Flex-GTR-protot 8 [SN03]							
Flex-GTR-protot 9 [SN03]							
Flex-GTR-protot 10 [SN03]							
Flex-GTR-protot 11 [SN03]							
Flex-GTR-protot 12 [SN03]							
Flex-GTR-protot 13 [SN03]							
BWVC02-01							
BWVC02-2							
BWVC02-3							
BWVC03-1							
BWVC03-2							
BWVC03-3							
BWVPR1-1							
BWVPR1-2							
BWVPR1-3							

- 14 out of 31 certification tests passed the Complete set of defined criteria
- 17 out of 31 certification tests failed one or two of the criteria
- The defect strain gauge of Tibia A3 of SN03 signed responsible for nine failed certification tests as the „unique“ reason
- When eliminating Tibia A3 of SN03 as reason for failing the certification test, 8 out of 31 tests failed the criteria

74 % passed  
26 % failed

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## Finalisation of certification corridors



Verification of certification corridor (Application to 31 Flex-GTR tests):

*8.2.3.3.1. When the lower legform impactor is used for the test specified in paragraph 8.2.3.4., the maximum bending moment of the tibia at tibia-1 shall be not more than 277 Nm and not less than 237 Nm, the maximum bending moment at tibia-2 shall be not more than 269 Nm and not less than 223 Nm, the maximum bending moment at tibia-3 shall be not more than 204 Nm and not less than 176 Nm, and the maximum bending moment at tibia-4 shall be not more than 120 Nm and not less than 98 Nm.*

*The maximum elongation of the MCL shall be not more than 23 mm and not less than 18 mm, that of the ACL shall be not more than 10.5 mm and not less than 8.5 mm, and that of the PCL shall be not more than 6 mm and not less than 4.5 mm.*

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**Summary**

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## Summary



- The procedure and test parameters for the inverse certification test have been described for the purpose of implementation within the text of the GTR
- The impact parameter tolerances for the inverse certification test have been verified and partly refined for the purpose of implementation within the text of the GTR
- Alternative honeycomb material for the inverse certification test has been assessed and defined for the purpose of implementation within the test of the GTR
- The inverse certification corridors have been fixed, taking into account all available and provided test data
- An equal weighting (i.e. the same number of test results) of the impactors taken into account is not really necessary, because the corridors are based on the achieved minimum and maximum values

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Thank you !

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