ESIS - TC24

LUCCHINI RS

Design of a freight axle with increased inspection intervals

FreiSet

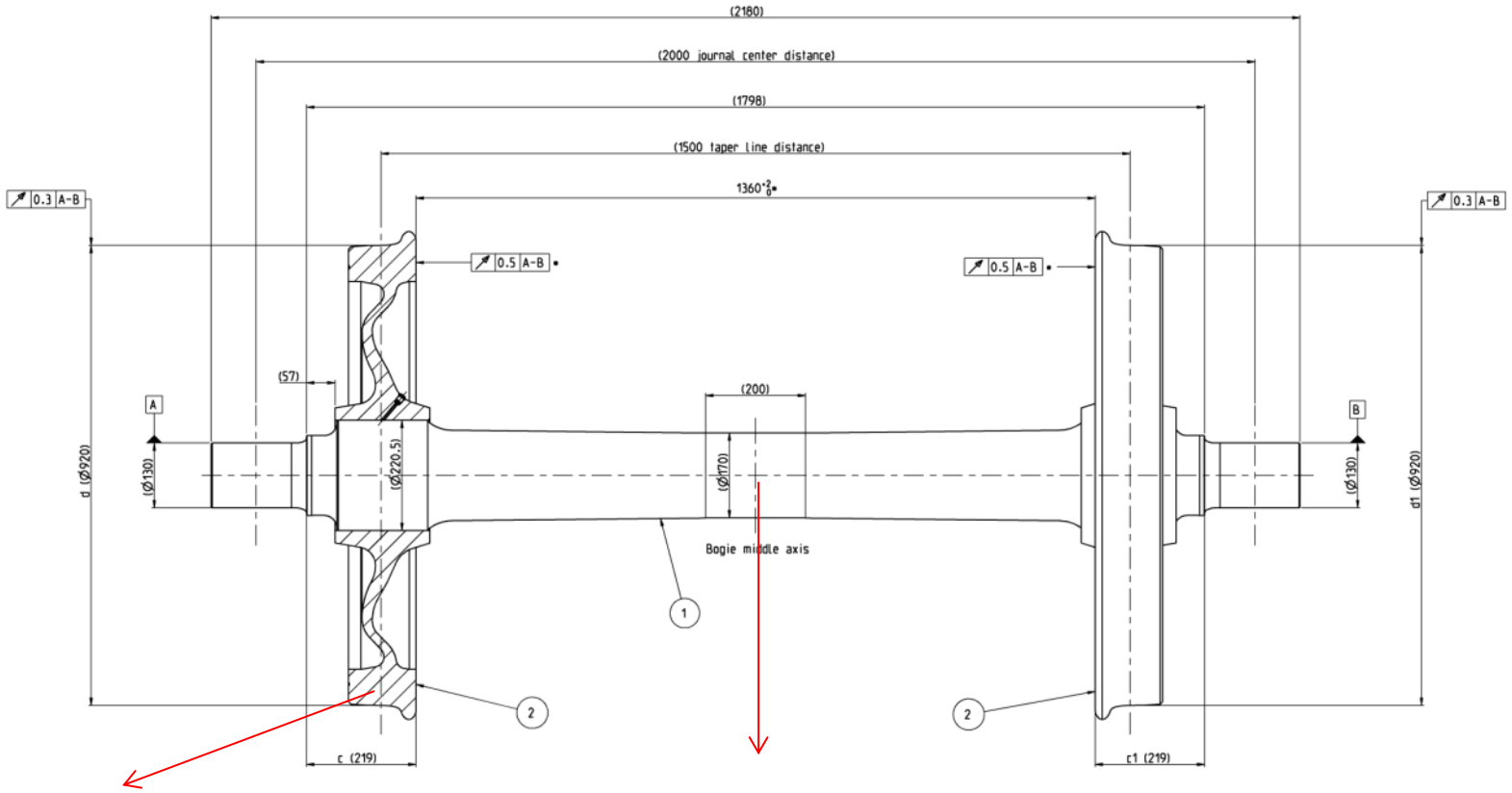
Steven Cervello - Lucchini RS

Summary

- Design of an innovative freight wheelset “Freiset”
  - Axle load up to 25 ton
  - Increased safety factor
  - EA1N steel grade
- Experimental investigation to verify optimal NDT inspection interval based on axle design, i.e. from 600.000 km to 1.200.000 km (IS3: changing of wheels)
- Option to improve axle surface protection by special anti impact coating “Lursak”

FreiSet Innovative freight wheelset

LUCCHINI RS



Sura

EN13979, TSI certified

LAx 141

Optimized geometry

The axle:

	Axle load	Axle	Wheel	Wheelset	Max stress in the transition (EN 13103) new and min diameter
BA302	25 ton	397 kg	362 kg	1121 kg	158,4 / 164 MPa
BA302	22,5 ton	397 kg	362 kg	1121 kg	142,6 / 147,6 MPa
Freiset	25 ton	419 kg	354 kg	1127 kg	140,6 MPa
Freiset	22,5 ton	419 kg	354 kg	1127 kg	125,8 MPa

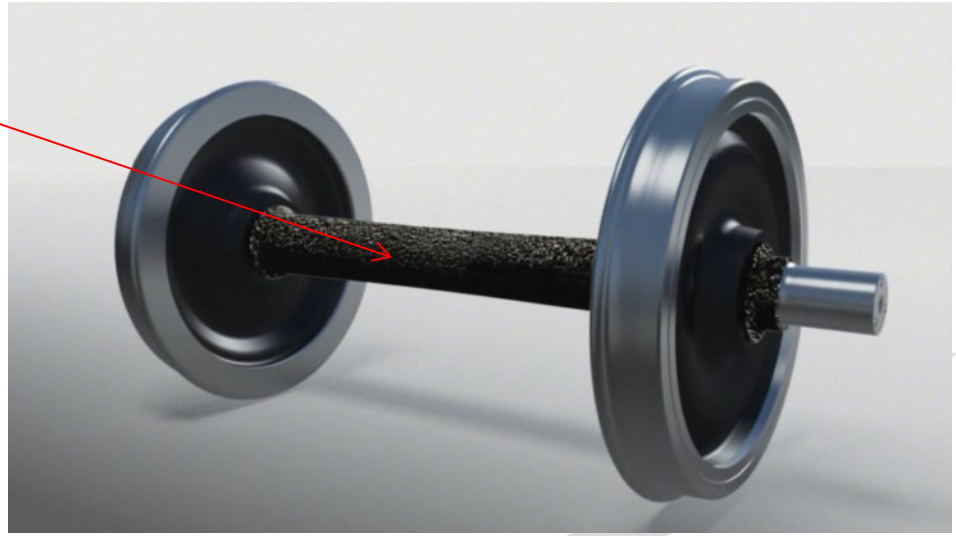
- Calculation based on EN13103
- Non guiding wheelset
- Centre of mass 2600 mm
- Braking force: 40 kN on one side

The coating

In order to limit the possibility that larger defects (than the one considered in the crack propagation tests) can take place in service, Lursak coating is used

Lursak®

- Anti ballast impact coating derived from railway high speed application
- Epoxy base, fibers reinforced
- Thickness ≈ 4 mm
- Pull-off strength > 5 MPa
- Fire resistant EN 45545
- Protects permanently the axle from corrosion and mechanical damages
- The application is extended to the collars sealing the labyrinth ring

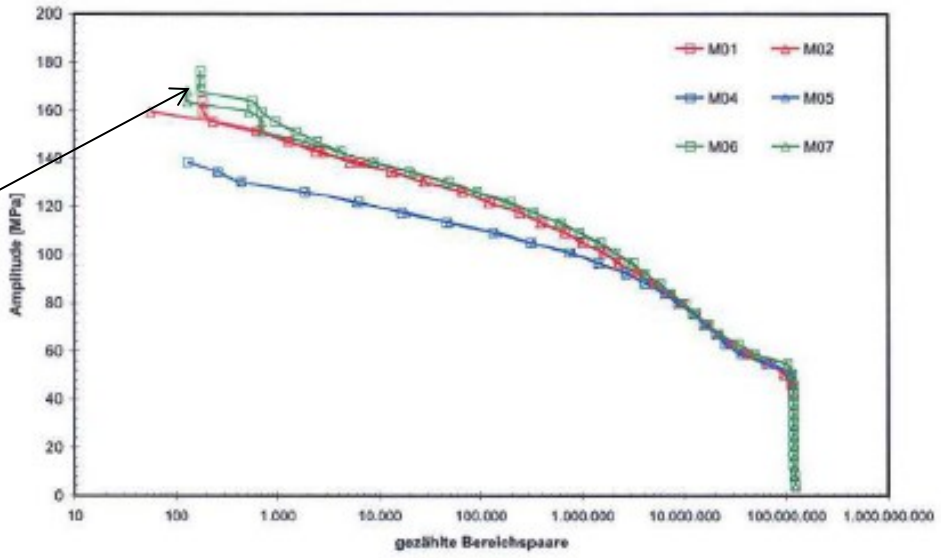


Crack propagation test

Load spectra – report UIC B 169/RP36

The load spectra is derived from the one available in the UIC report (UIC B 169/RP 36) .

The load measurements were made through various German railway lines on a BA302 (22,5 ton axle load).



Axle transition

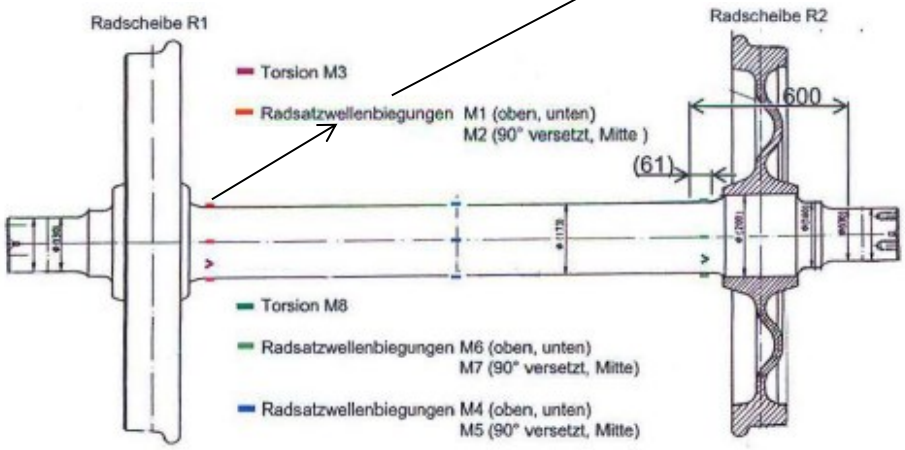


Figure 2.3.1 c: Axle measurement points

The load spectra is nominal stress at transitions.
The load spectra was scaled to reproduce the Freiset geometry and the 22,5 and 25 ton axle load condition.

Crack propagation test

Load spectra – defined by DB

The load spectra in the UIC report is nominal stress as measurements are made at 80 mm from the seat edge

Hypothesis at the basis of the spectra:

- The vehicle is 100% of km fully loaded at 22,5 or 25 ton

- The wheelset is 50% of km guiding, 50% non guiding

- The wheelset has always wheel diameter of 0.850 m
  (last reprofling diameter)

  in 15.000 km:
  0.920 mm → 5.189.835 cycles
  0.850 mm → 5.617.233 cycles

Crack propagation test

Load spectra 22.5 and 25 ton

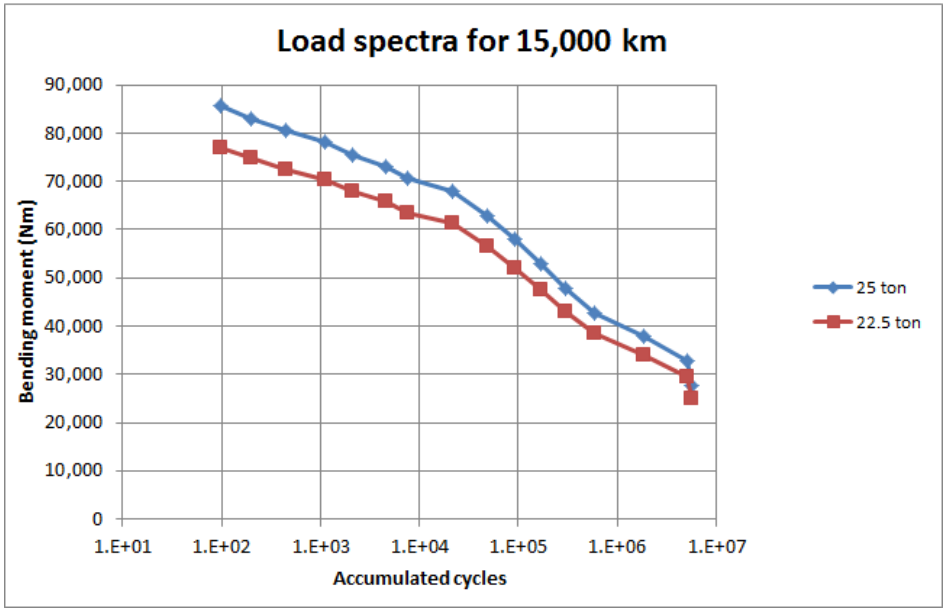
Straight running condition,
most frequent,
equivalent to static axle load

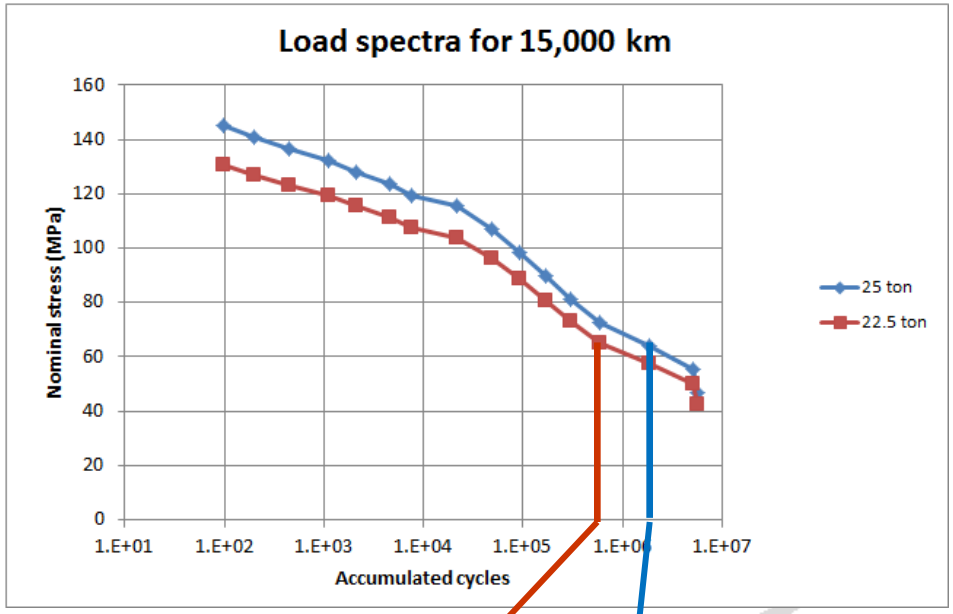
						D =	181
Axle load (ton)	22.5	Distance	Distance	Bending moment	Actuator force	W =	582151
Load level		15,000	1,200,000	BM	F	Snom	Sloc
Nr	Cycles	Cumulative cycles	Cumulative cycles	Nm	kN	MPa	MPa
1	434,891	5,629,213	450,337,040	24,917	57.7	42.8	50.7
2	3,306,606	5,194,322	415,545,760	29,446	68.6	50.6	59.9
3	1,299,875	1,887,716	151,017,280	33,977	79.4	58.4	69.1
4	283,726	587,841	47,027,280	38,507	90.3	66.1	78.3
5	134,182	304,115	24,329,200	43,094	101.3	74.0	87.6
6	76,306	169,933	13,594,640	47,624	112.2	81.8	96.8
7	45,606	93,627	7,490,160	52,154	123.1	89.6	106.1
8	26,616	48,021	3,841,680	56,685	133.9	97.4	115.3
9	13,853	21,405	1,712,400	61,214	144.8	105.2	124.5
10	2,961	7,552	604,160	63,480	150.2	109.0	129.1
11	2,457	4,591	367,280	65,745	155.7	112.9	133.7
12	1,005	2,134	170,720	68,010	161.1	116.8	138.3
13	680	1,129	90,320	70,275	166.5	120.7	142.9
14	251	449	35,920	72,540	172.0	124.6	147.5
15	101	198	15,840	74,805	177.4	128.5	152.1
16	97	97	7,760	77,071	182.9	132.4	156.7
					Smax EN	126.5	
				Smax EN/Smax spectra		0.956	

						D	181
Axle load (ton)	25	Distance	Distance	Bending moment	Actuator force	W	582151
Load level		15,000	1,200,000	BM	F	Snom	Sloc
Nr	Cycles	Cumulative cycles	Cumulative cycles	Nm	kN	MPa	MPa
1	434,891	5,629,213	450,337,040	27,685	64.3	47.6	56.3
2	3,306,606	5,194,322	415,545,760	32,718	76.4	56.2	66.5
3	1,299,875	1,887,716	151,017,280	37,752	88.5	64.8	76.8
4	283,726	587,841	47,027,280	42,785	100.6	73.5	87.0
5	134,182	304,115	24,329,200	47,882	112.8	82.3	97.4
6	76,306	169,933	13,594,640	52,915	124.9	90.9	107.6
7	45,606	93,627	7,490,160	57,949	137.0	99.5	117.8
8	26,616	48,021	3,841,680	62,983	149.0	108.2	128.1
9	13,853	21,405	1,712,400	68,016	161.1	116.8	138.3
10	2,961	7,552	604,160	70,533	167.2	121.2	143.4
11	2,457	4,591	367,280	73,050	173.2	125.5	148.6
12	1,005	2,134	170,720	75,567	179.2	129.8	153.7
13	680	1,129	90,320	78,083	185.3	134.1	158.8
14	251	449	35,920	80,600	191.3	138.5	163.9
15	101	198	15,840	83,117	197.4	142.8	169.0
16	97	97	7,760	85,634	203.4	147.1	174.1
					Smax EN	141.2	
				Smax EN/Smax spectra		0.960	

Crack propagation test

Load spectra 22.5 and 25 ton



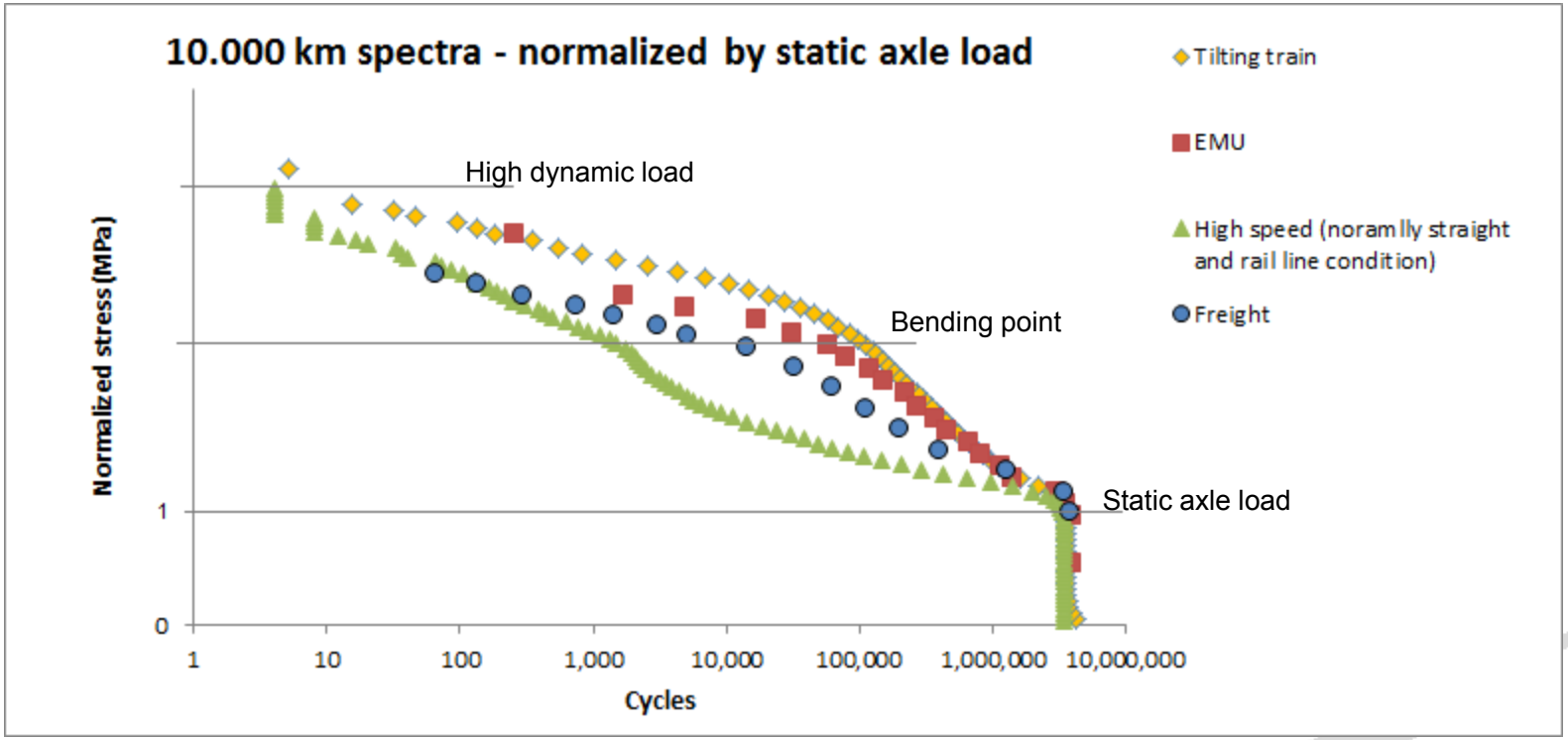


587,841 cycles per repetition equal to 15,000 km
47,000,000 cycles per 1,200,000 km

1.887,716 cycles per repetition equal to 15,000 km
151,000,000 cycles per 1,200,000 km

Crack propagation test

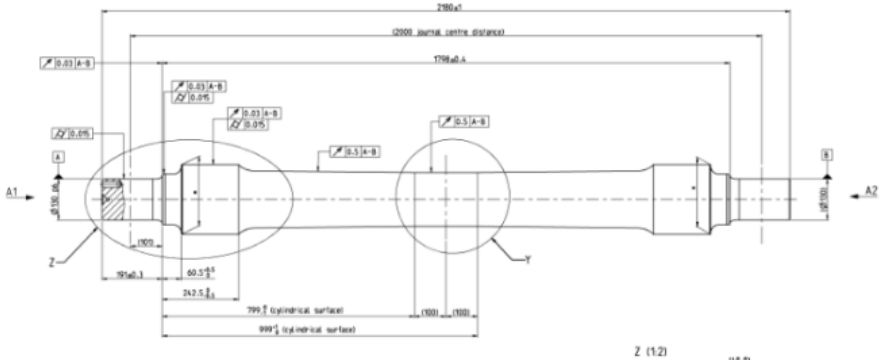
Load spectra comparison



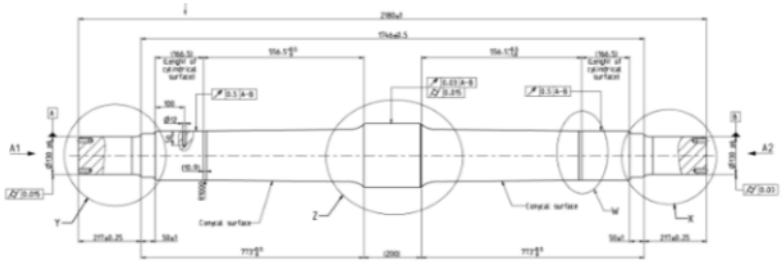
The crack propagation here presented is valid for:

- a spectra of a defined shape (it can be scaled to the static load)
- EA1N

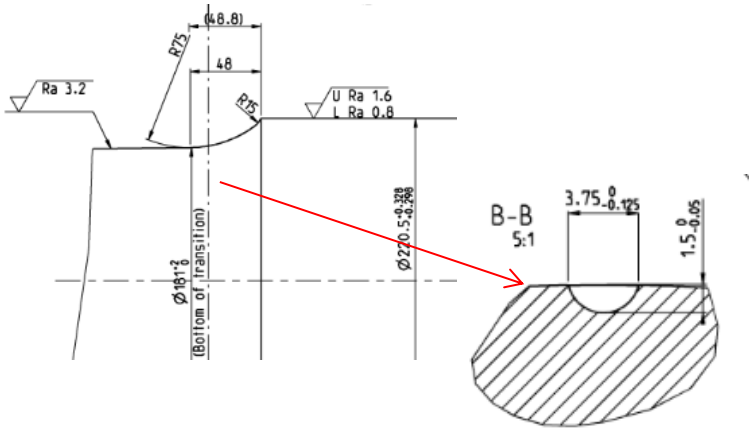
Crack propagation test
Axle component for test



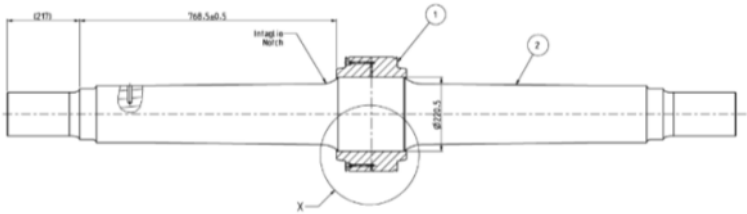
Original Freiset axle drawing



Axle for BDA test rig riproducing
Freiset wheelseat/ body geometry

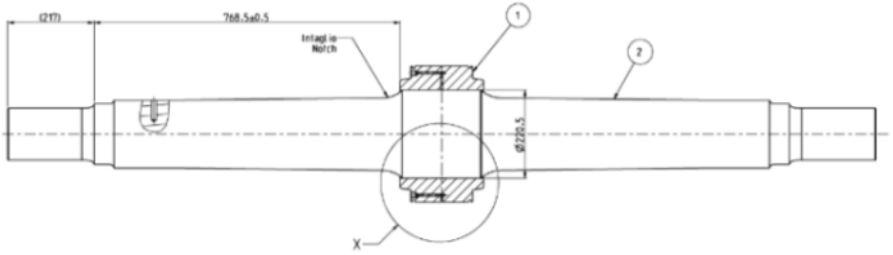


N° 3 artificial notch in the critical transition section, 120° from each other

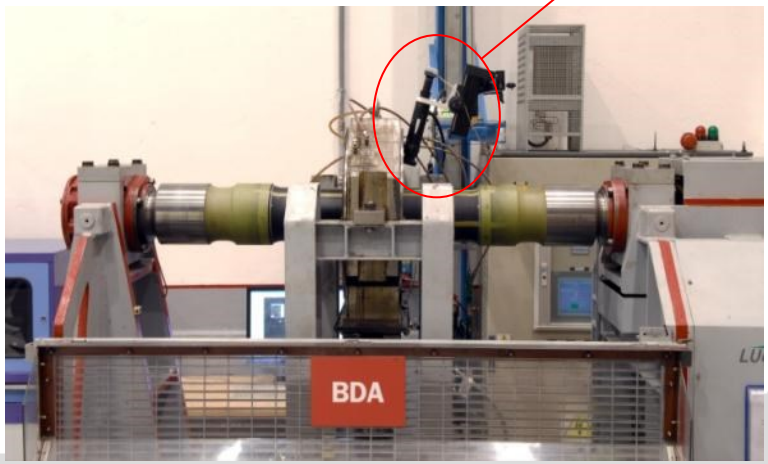


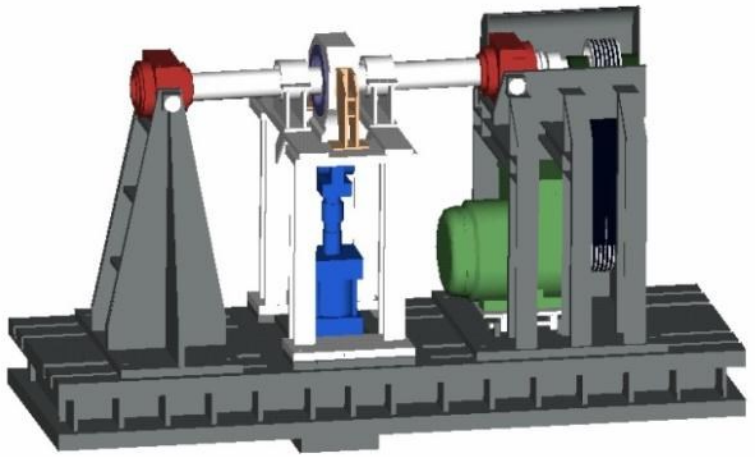
Assembly of hub to reproduce press fit stresses

Crack propagation test
BDA test rig



- The test is performed on the 3 point rotating bending test rig “BDA”.
- The load is applied in the middle by an hydraulic actuator.
- The crack propagation length is periodically measured by an electronic microscope.
- Rotation speed is reduced to 2 Hz while increasing load to the highest levels applying the correct number of cycles required (low)





Crack propagation test

Pre-cracking test

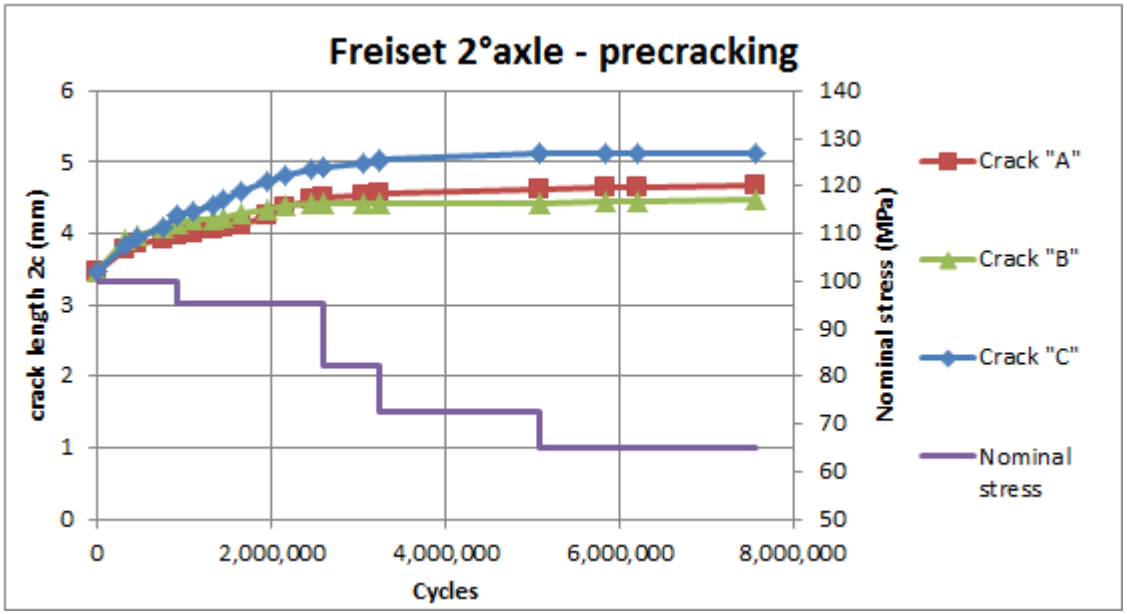
Crack A

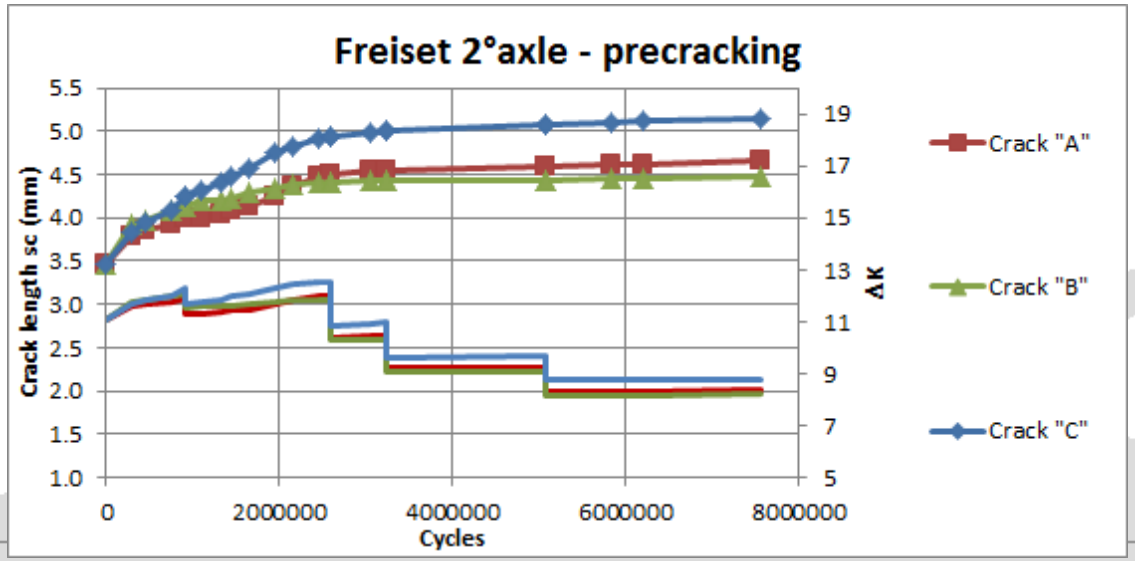
Crack B

Crack C

Crack propagation test

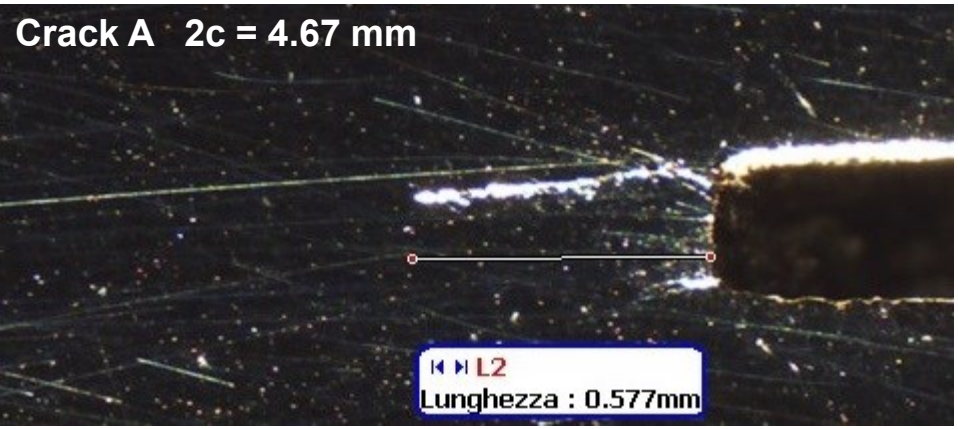
Pre-cracking test

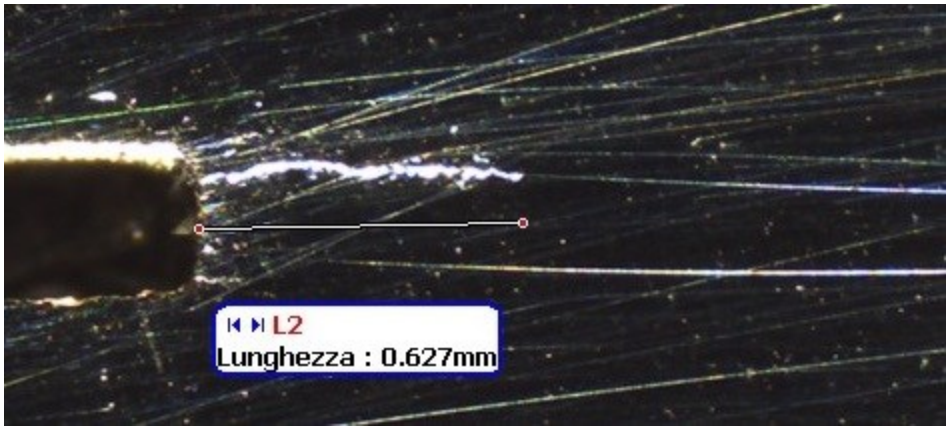


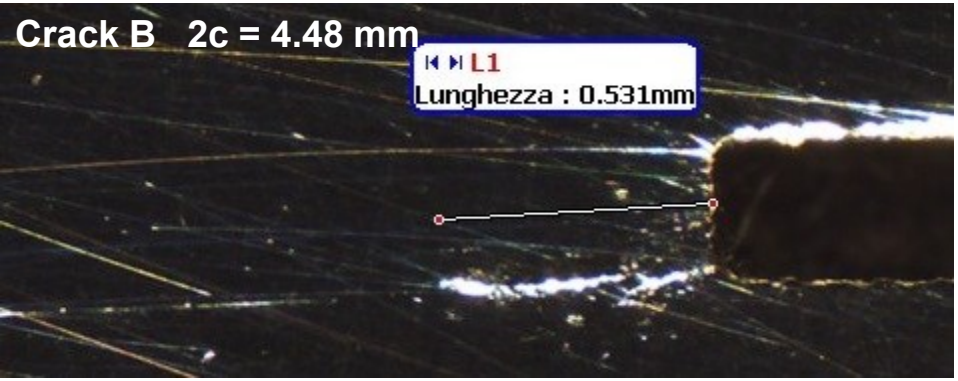


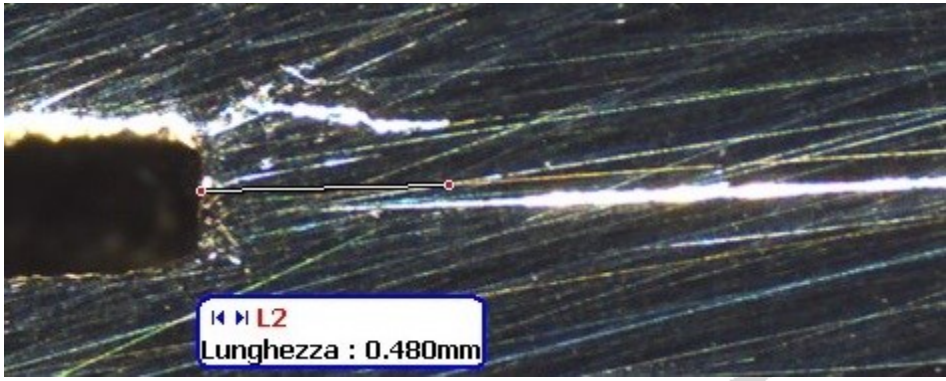
Crack propagation test

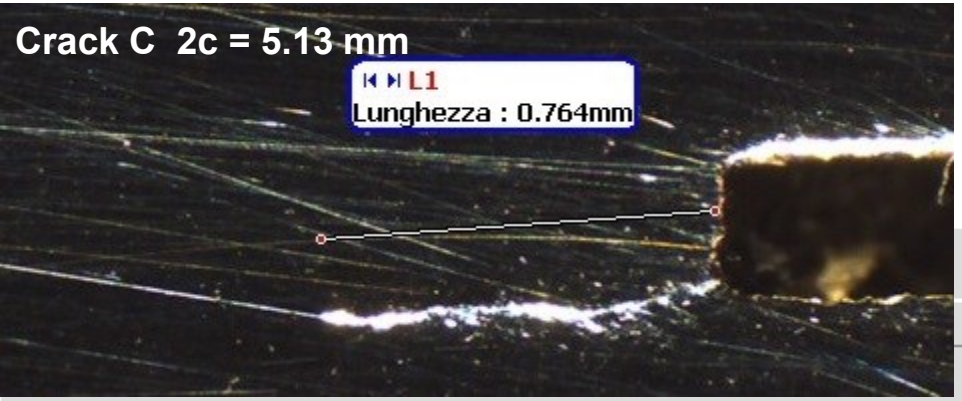
Pre-cracking test

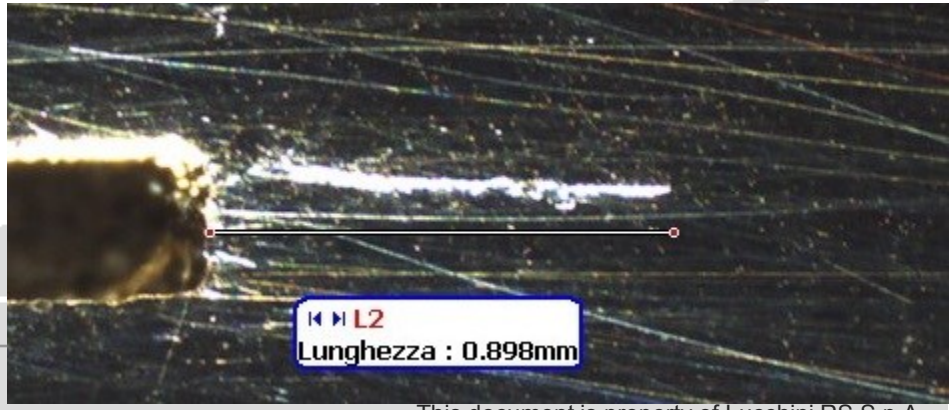






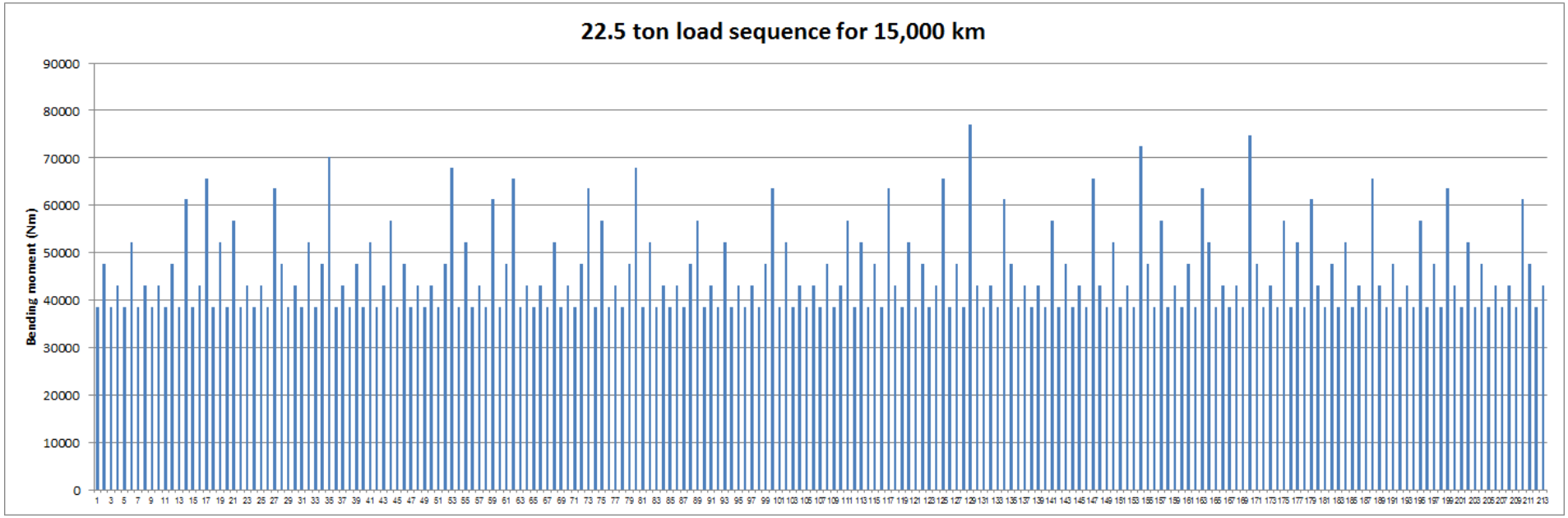


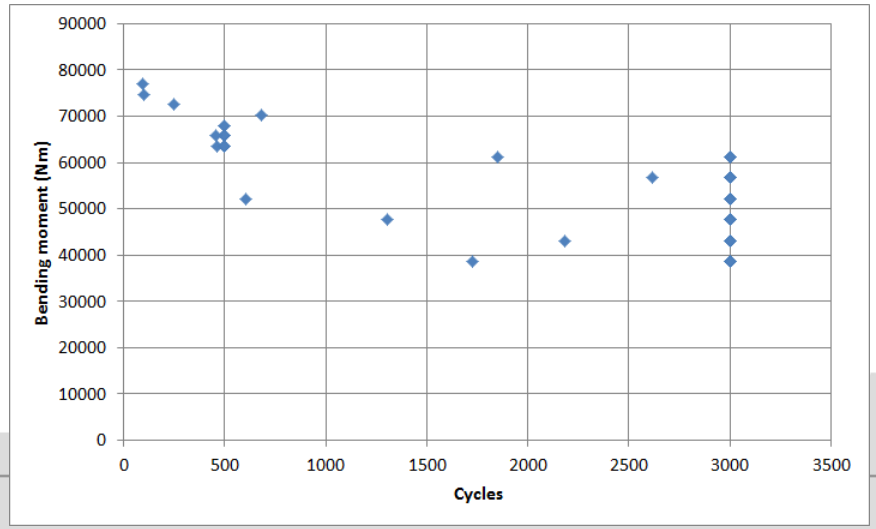




Crack propagation test

Propagation test at 22.5 ton spectra – Load sequence

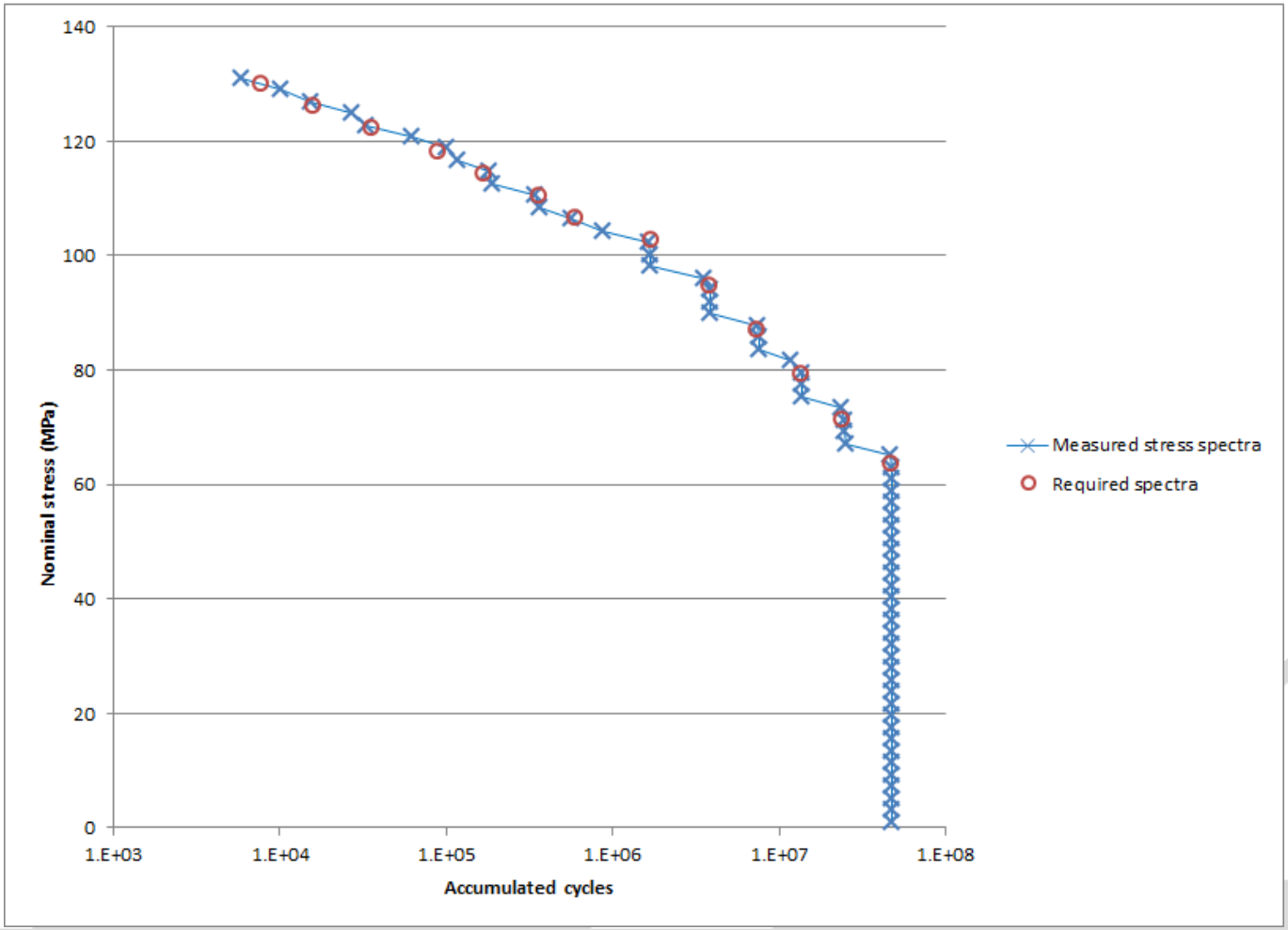




The sequence is repeated 80 times to reproduce 1.2 Mkm

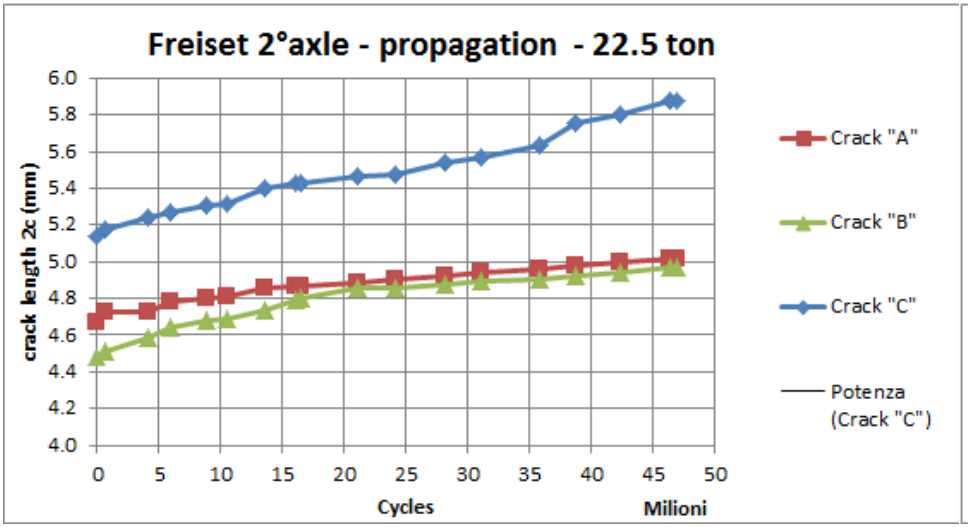
Crack propagation test

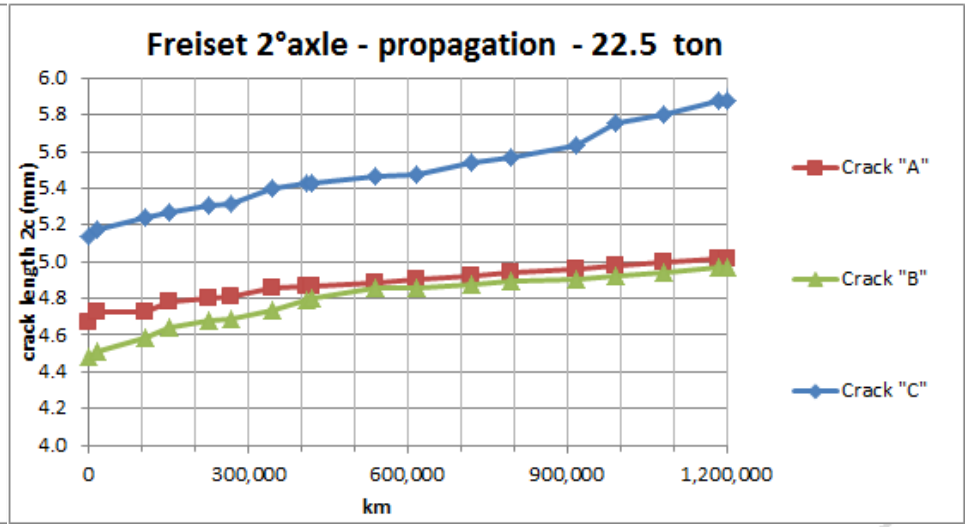
Propagation test at 22.5 ton spectra – Load sequence



Crack propagation test

Propagation test at 22.5 ton spectra



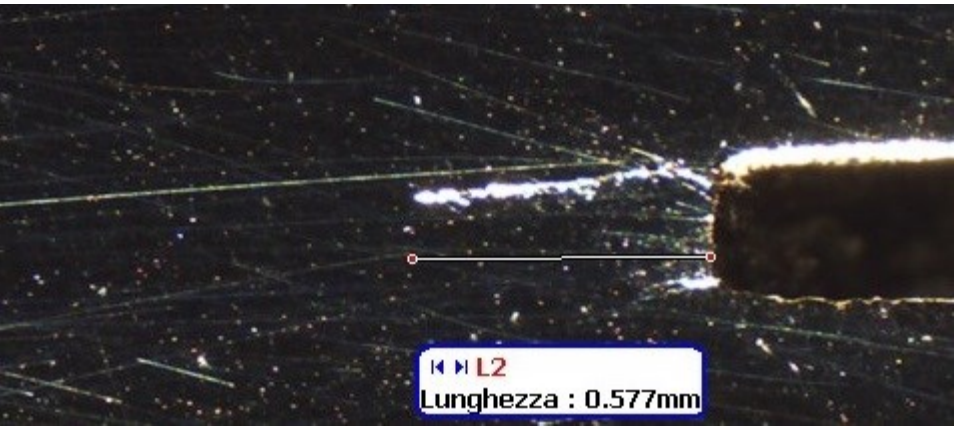


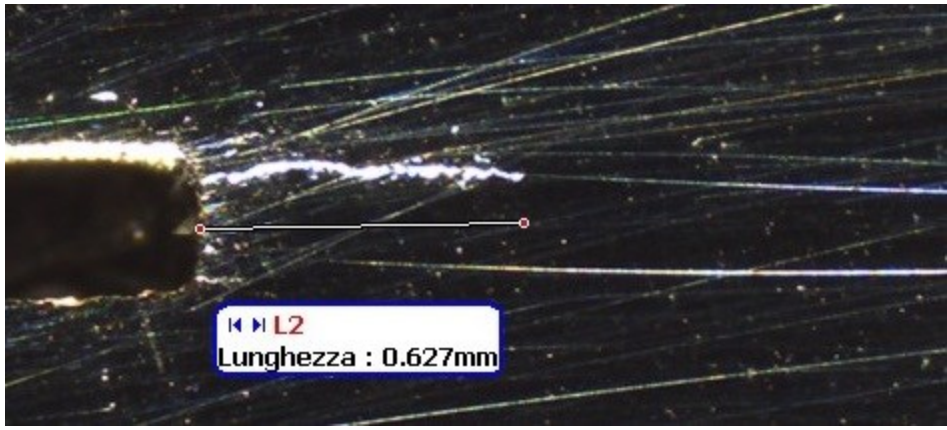
axle load ton	nom. Stress range	distance Mkm	A	B	C
22.5	131 - 65 Mpa	0.0	4.67	4.48	5.13
		1.2	5.02	4.97	5.88
		growth	0.35	0.49	0.75

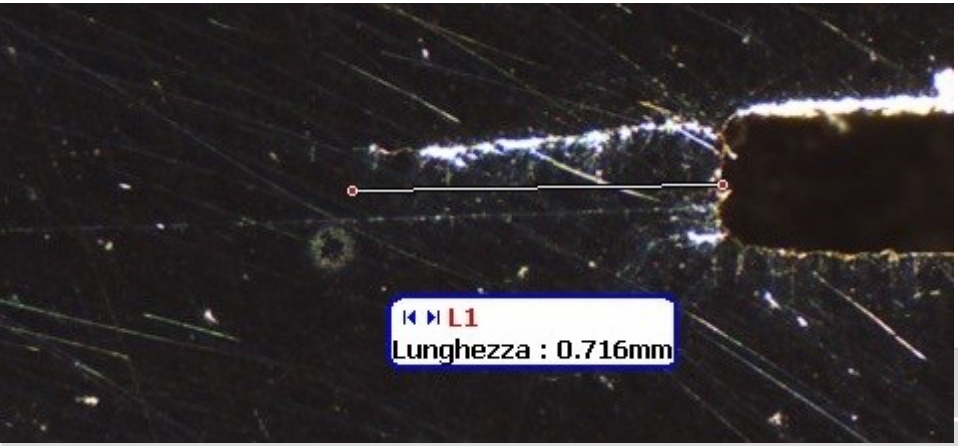
Crack propagation test

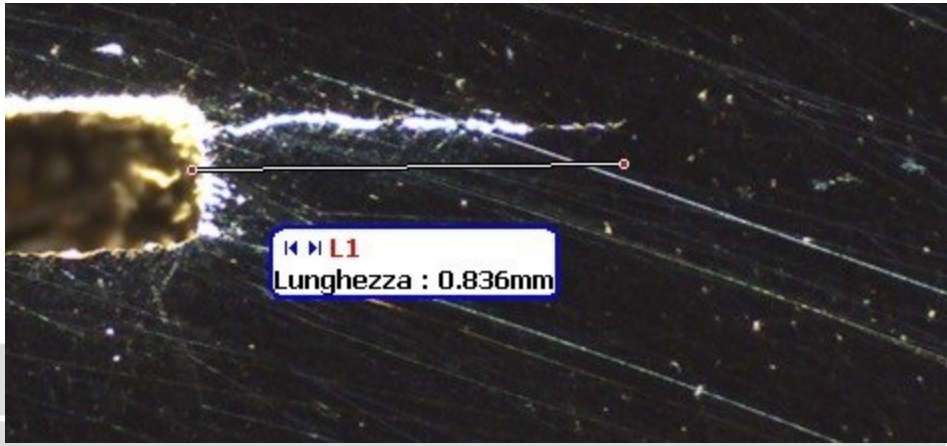
Propagation test at 22.5 ton spectra – Crack A after 1.2 Mkm

Crack A, 2c from 4.67 mm to 5.02 mm





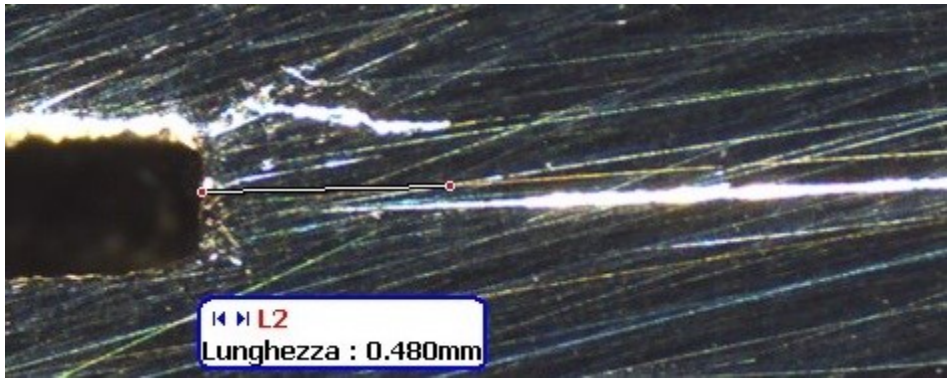


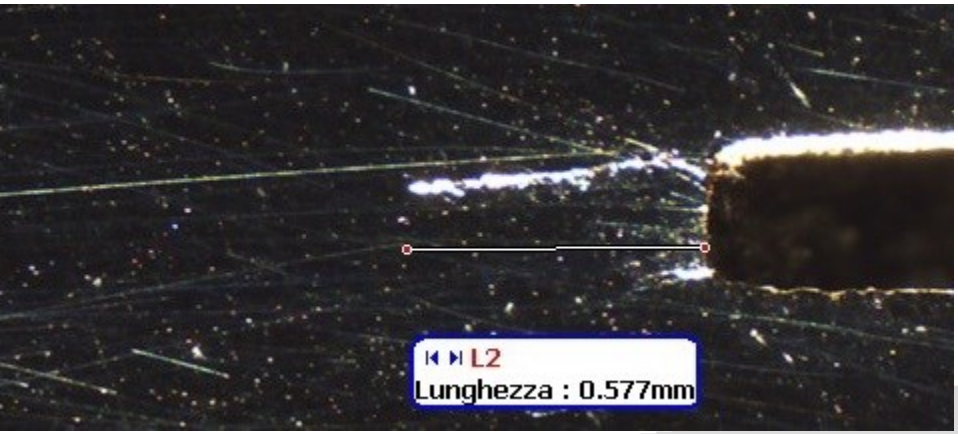


Crack propagation test

Propagation test at 22.5 ton spectra – Crack B after 1.2 Mkm

Crack B, 2c from 4.48 mm to 4.97 mm

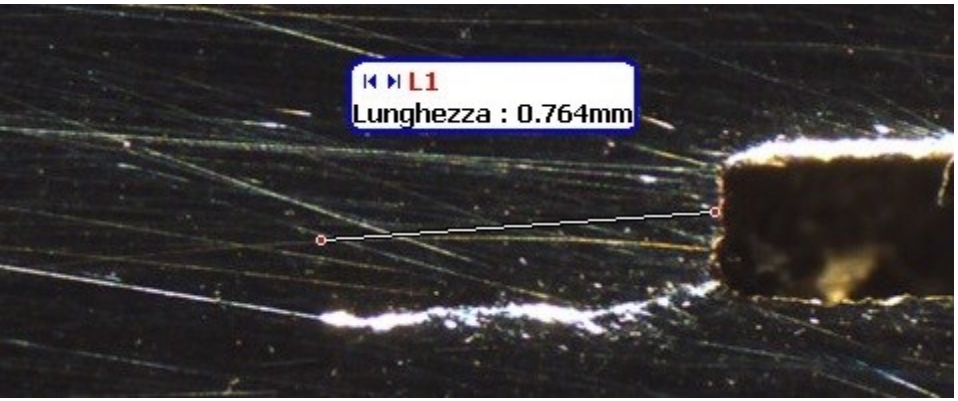


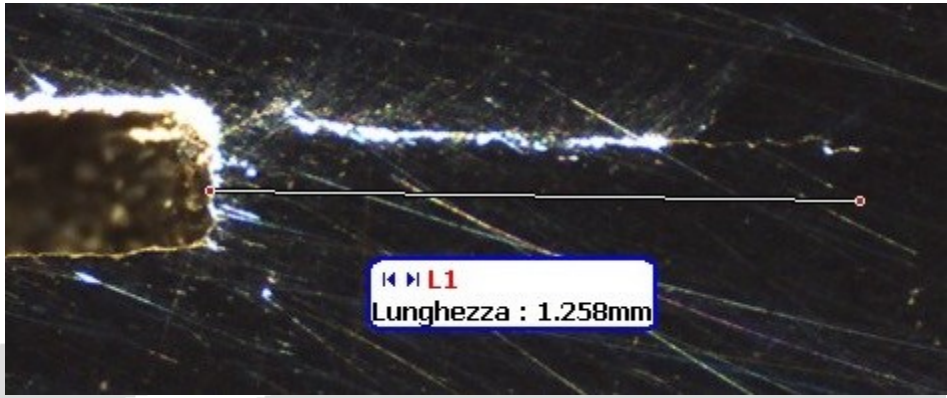


Crack propagation test

Propagation test at 22.5 ton spectra – Crack C after 1.2 Mkm

Crack C, 2c from 5.13 mm to 5.88 mm



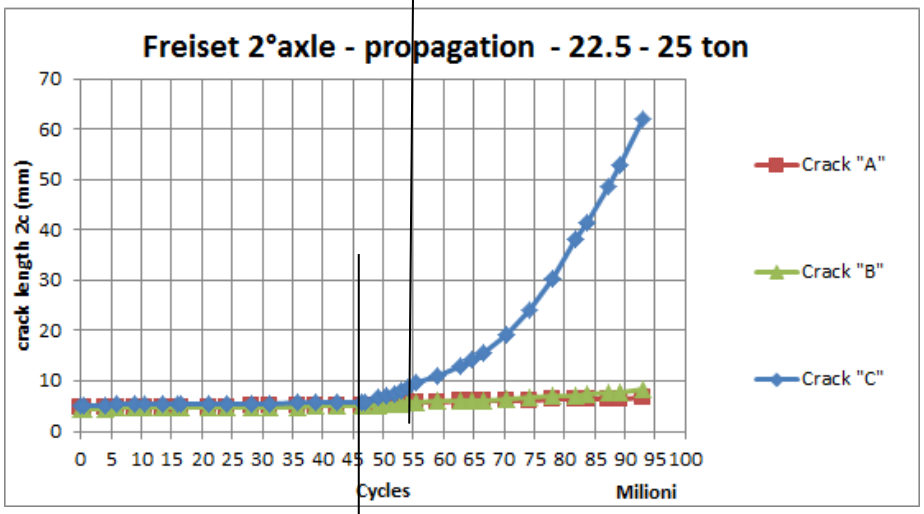


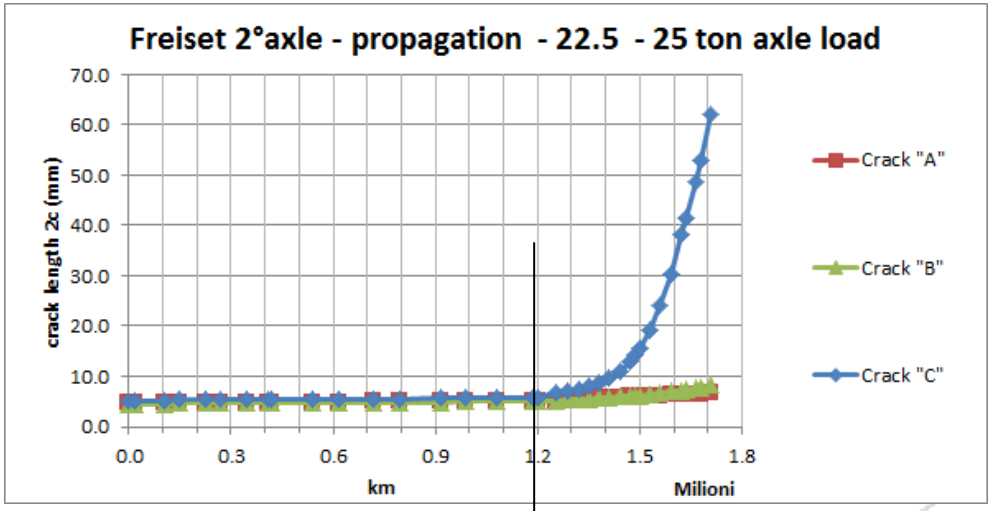
Crack propagation test

Continuation of propagation test, load increased to 25 ton spectra

587,841 cycles per repetition equal to 15,000 km

1.887,716 cycles per repetition equal to 15,000 km





22.5 ton | 25 ton

22.5 ton | 25 ton

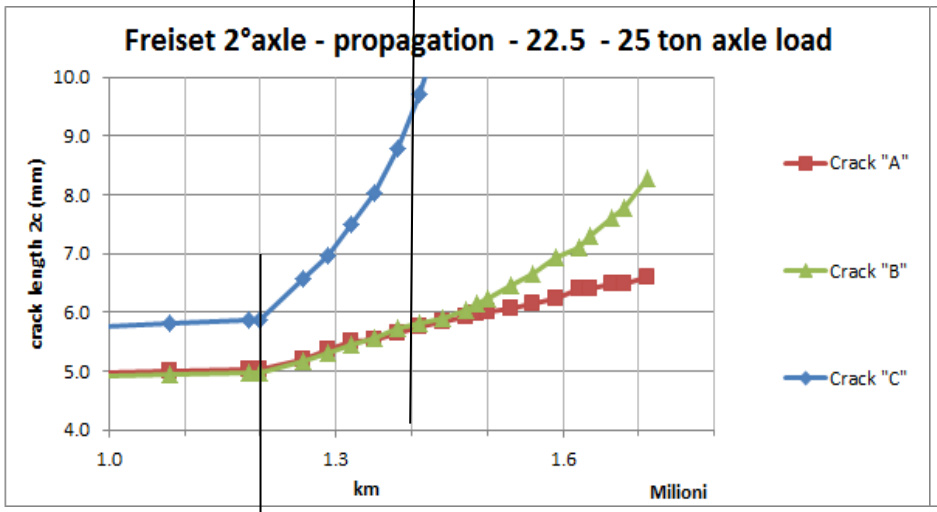
axle load ton	nom. Stress range	distance Mkm	A	B	C
22.5	132 - 66 Mpa	0.0	4.67	4.48	5.13
		1.2	5.02	4.97	5.88
		growth	0.35	0.49	0.75
25	147 - 73 Mpa	0.0	5.02	4.97	5.88
		+0.510	6.61	8.29	62.00
		growth	1.59	3.32	56.12

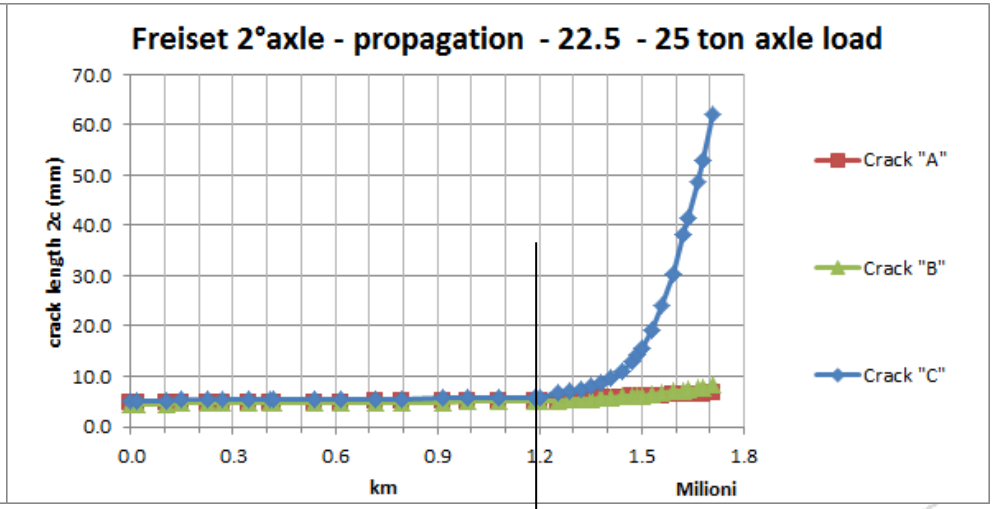
Crack propagation test

Continuation of propagation test, load increased to 25 ton spectra

587,841 cycles per repetition equal to 15,000 km

1.887,716 cycles per repetition equal to 15,000 km





22.5 ton | 25 ton

22.5 ton | 25 ton

axle load ton	nom. Stress range	distance Mkm	A	B	C
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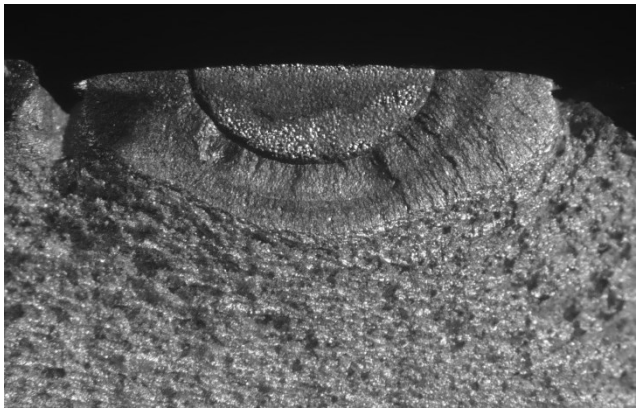
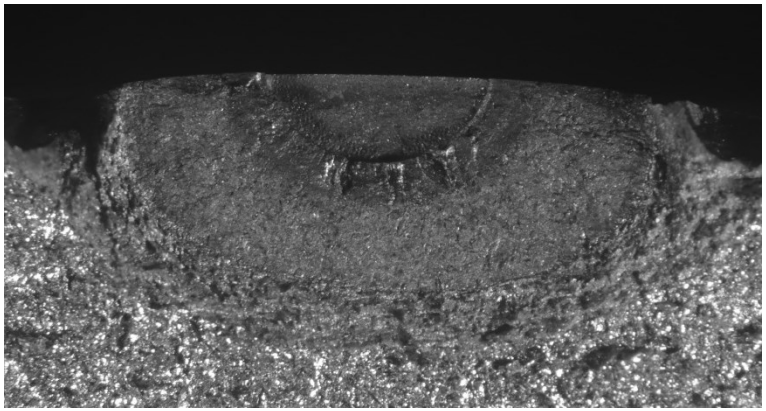
		1.2	5.02	4.97	5.88
		growth	0.35	0.49	0.75
25	147 - 73 Mpa	0.0	5.02	4.97	5.88
		+0.510	6.61	8.29	62.00
		growth	1.59	3.32	56.12

Crack propagation test

Opening of the cracks



Crack A



Crack B

axle load ton	nom. Stress range	distance Mkm	A	B	C
22.5	132 - 66 Mpa	0.0	4.67	4.48	5.13
		1.2	5.02	4.97	5.88
		growth	0.35	0.49	0.75
25	147 - 73 Mpa	0.0	5.02	4.97	5.88
		+ 0.510	6.61	8.29	62.00
		growth	1.59	3.32	56.12

Crack propagation test

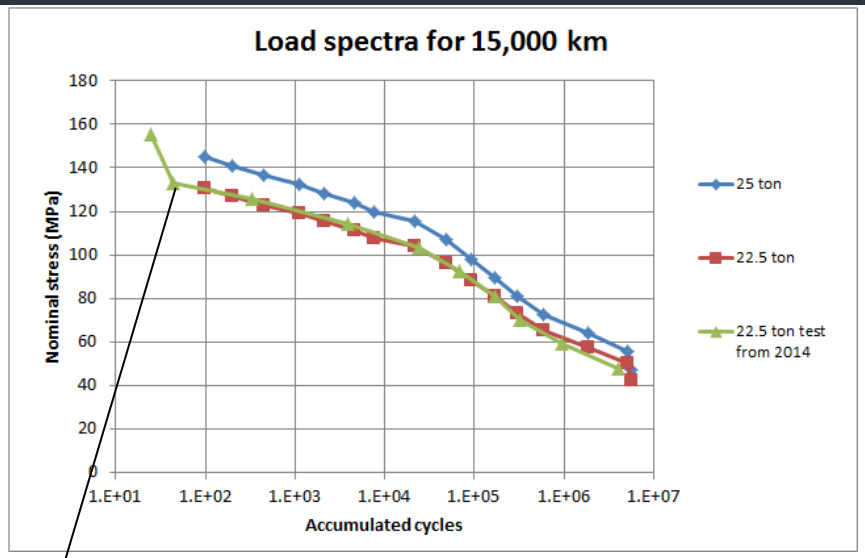
Opening of the cracks

Crack C

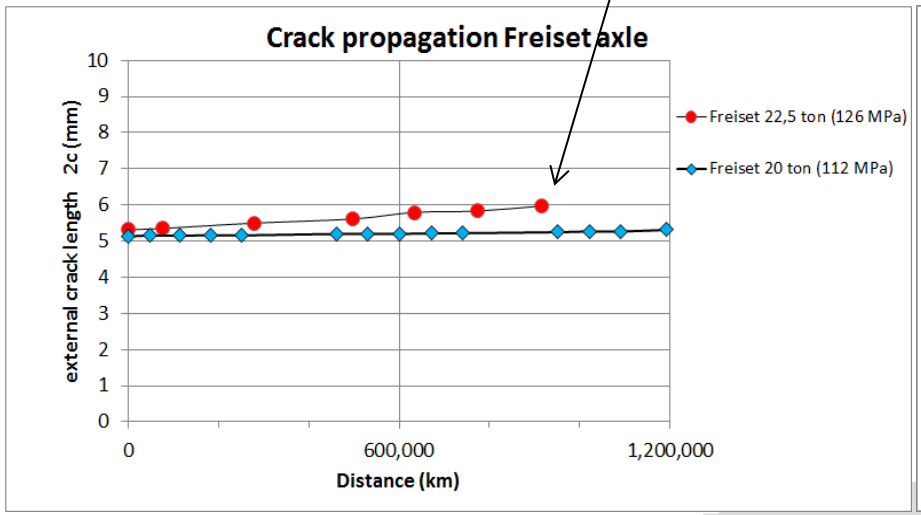
axle load ton	nom. Stress range	distance Mkm	A	B	C
22.5	132 - 66 Mpa	0.0	4.67	4.48	5.13
		1.2	5.02	4.97	5.88
		growth	0.35	0.49	0.75
25	147 - 73 Mpa	0.0	5.02	4.97	5.88
		+ 0.510	6.61	8.29	62.00
		growth	1.59	3.32	56.12

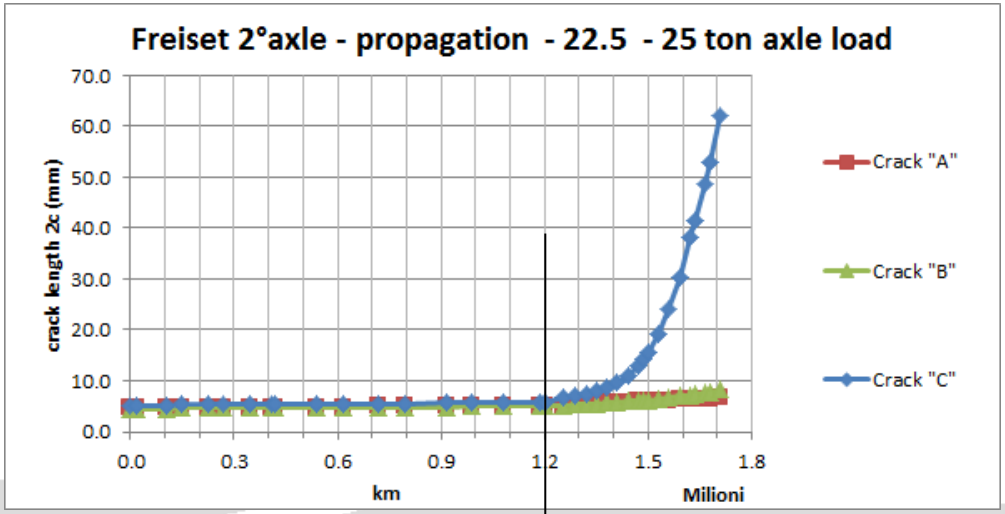
Crack propagation test

Comparison with previous tests made in 2015



Test results from 2015



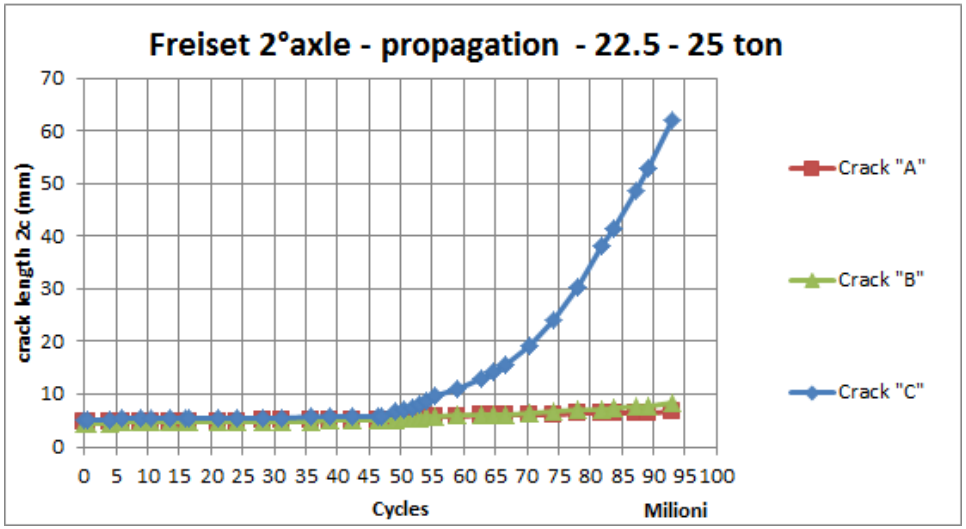


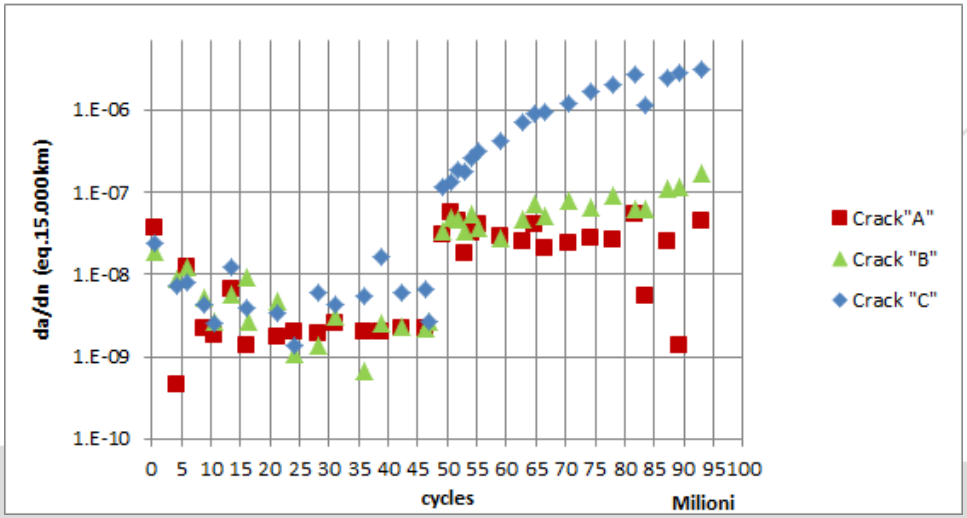
Good coherence in the results of the two tests at 22.5 ton

22.5 ton | 25 ton

Crack propagation test

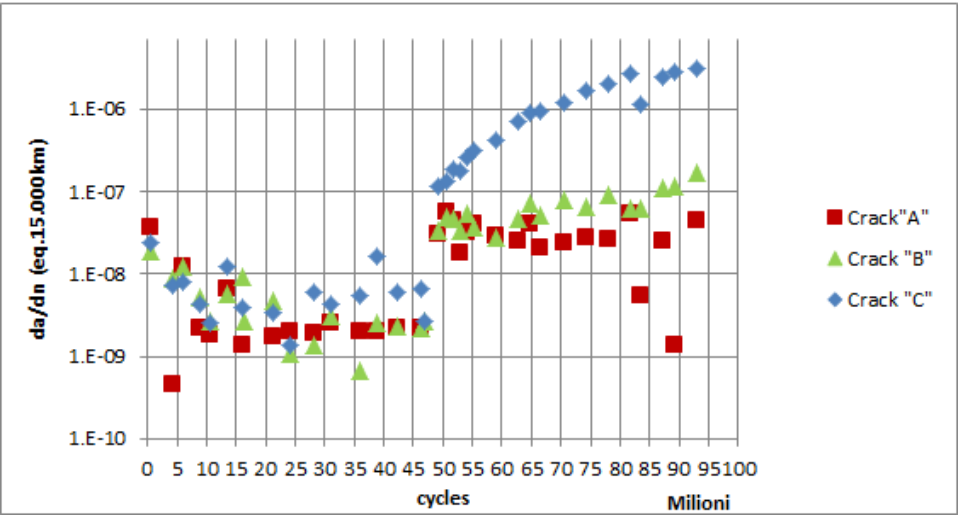
Crack speed

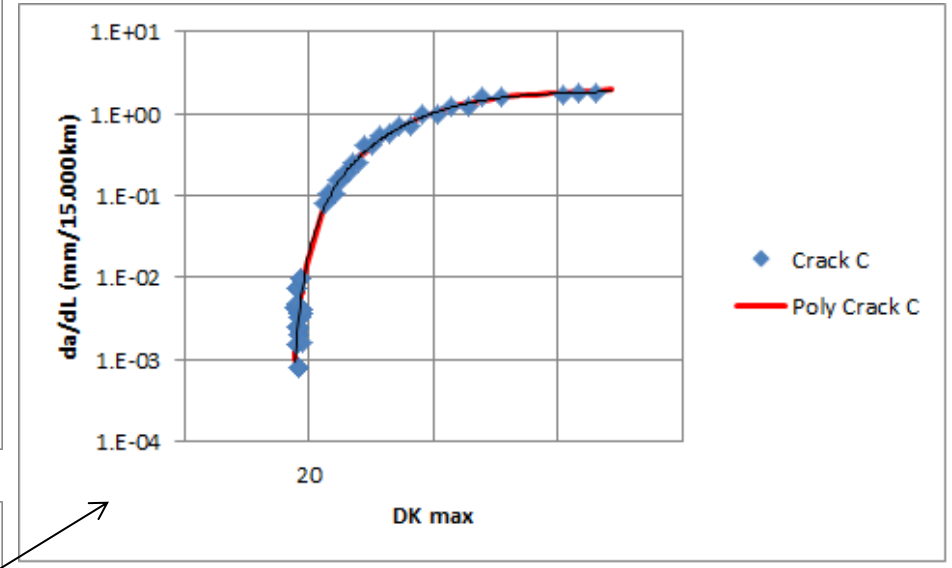


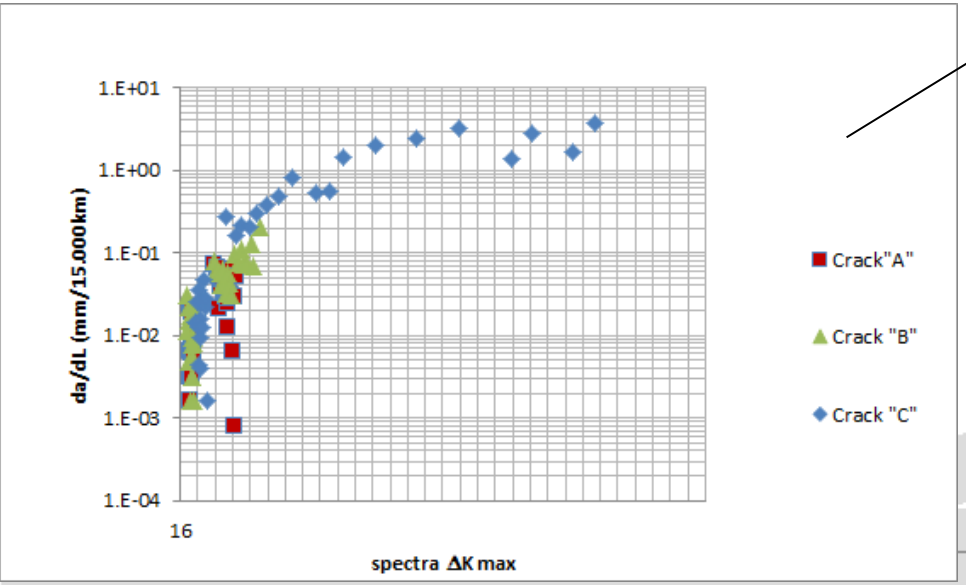


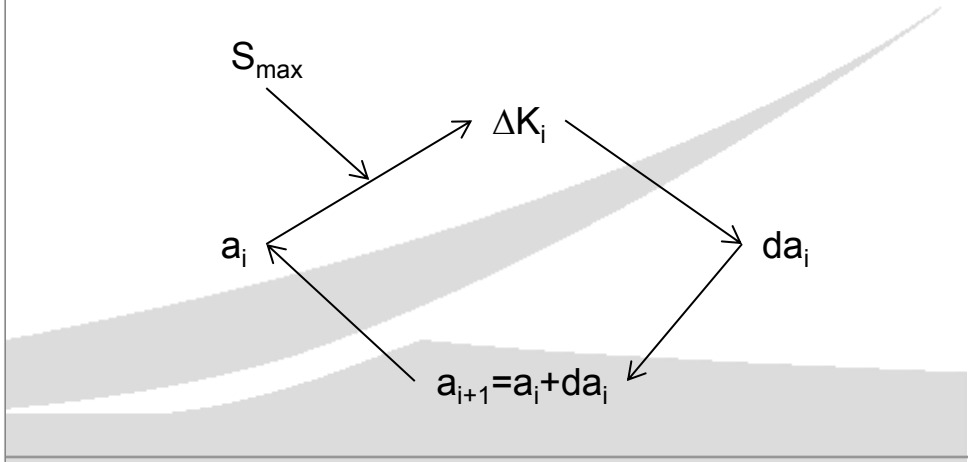
Crack propagation test

Crack speed per load sequence repetition



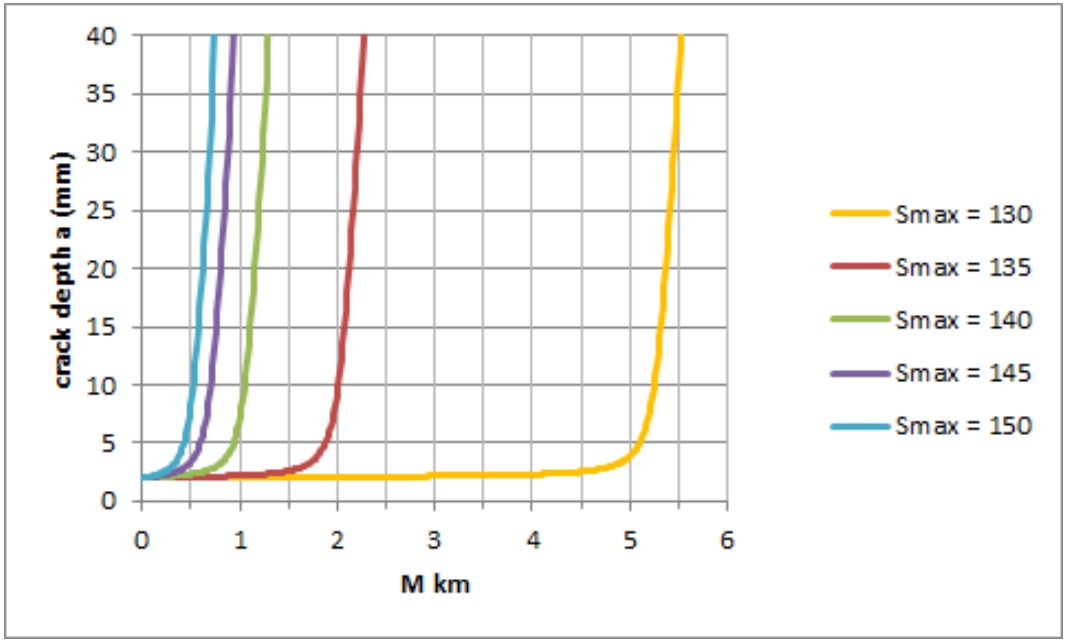


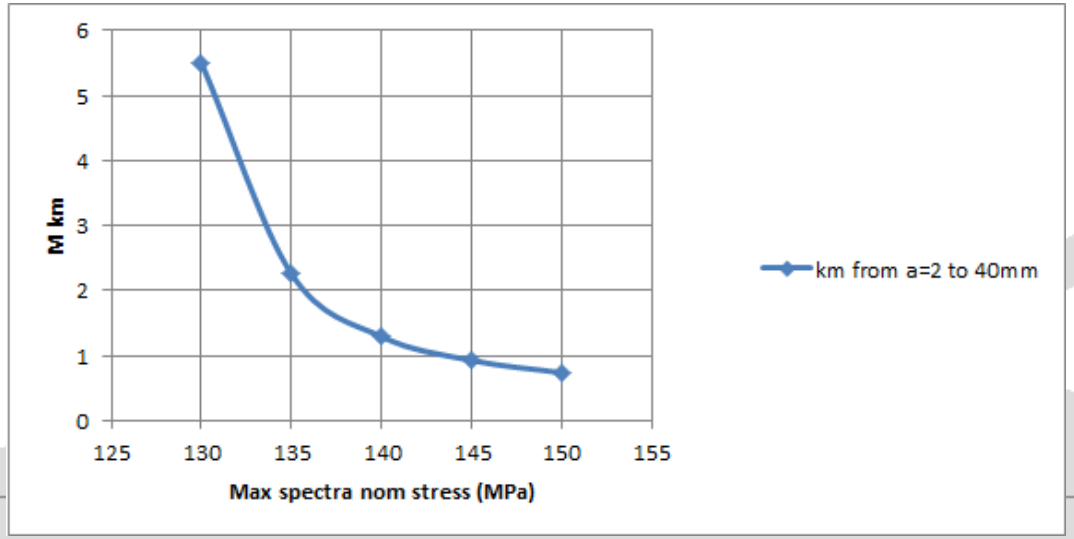




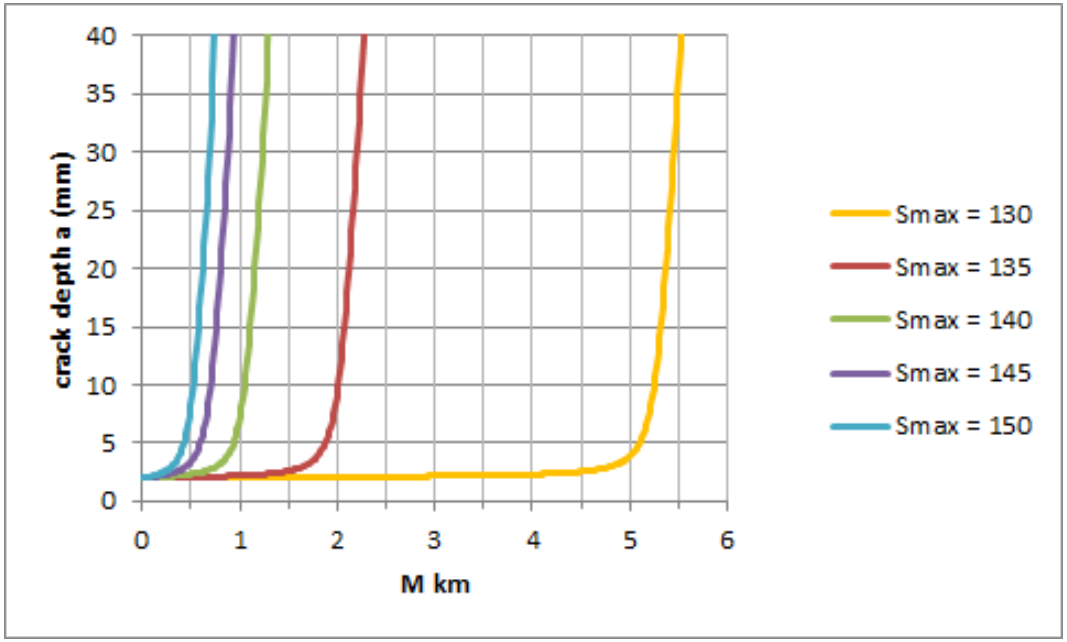
Crack propagation estimation

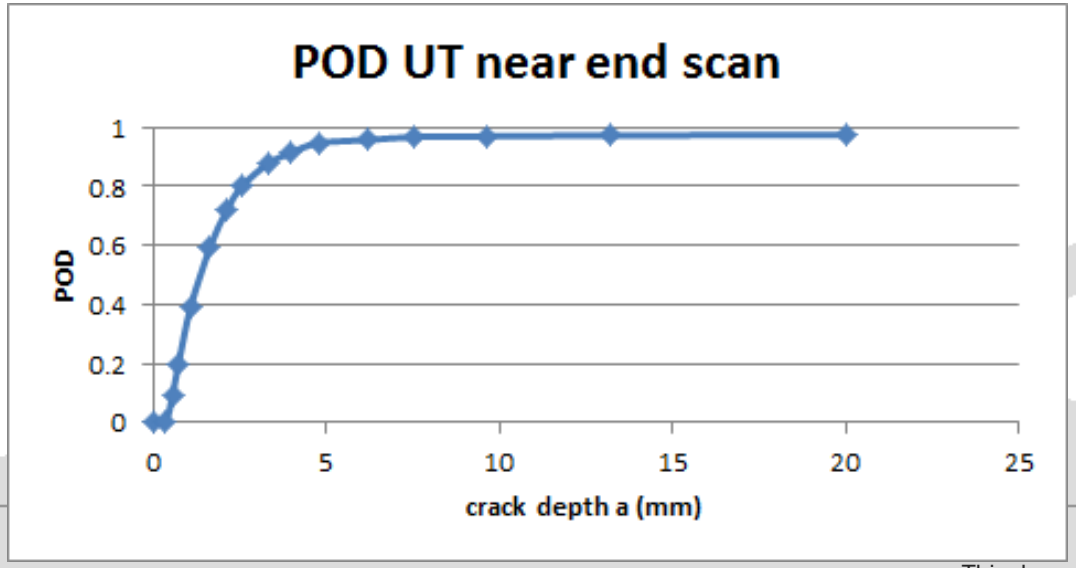
Starting from 2 mm deep cracks at different max stress spectra





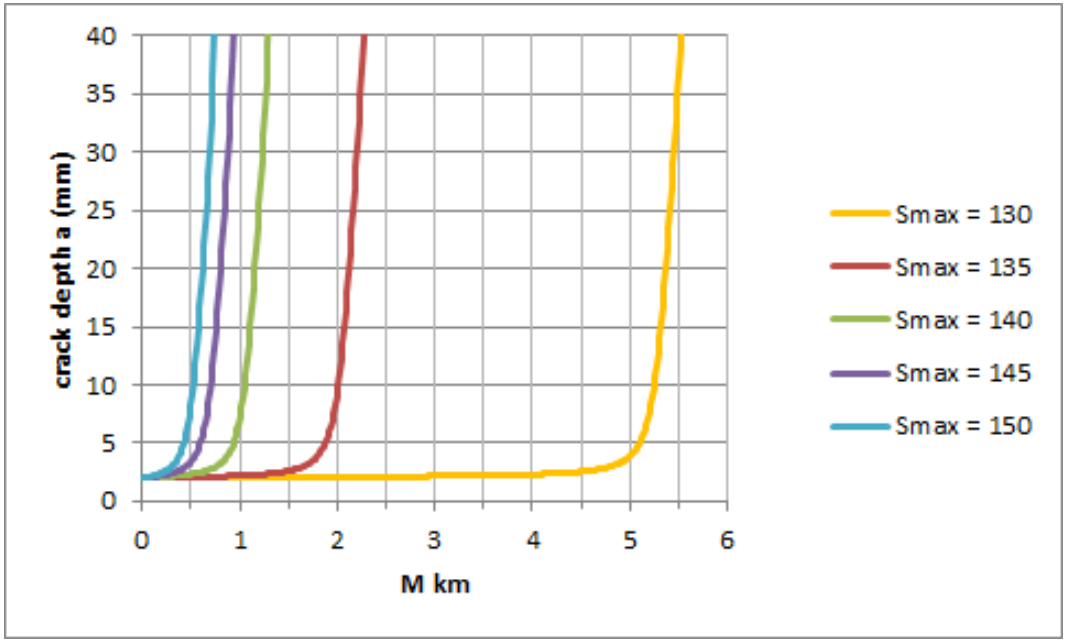
Probability of failure
based on POD at defined intervals

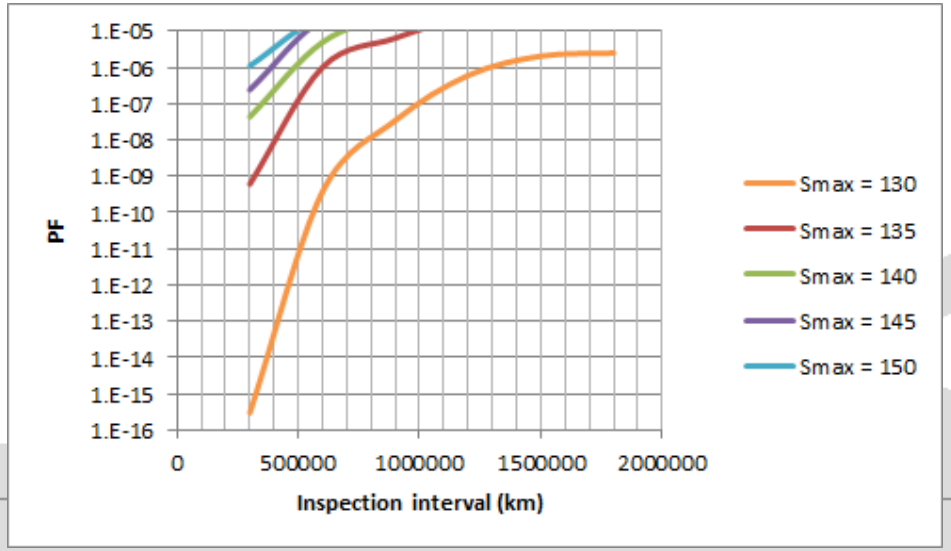




$$PF = \left(\prod_{n} POND_i \right)$$

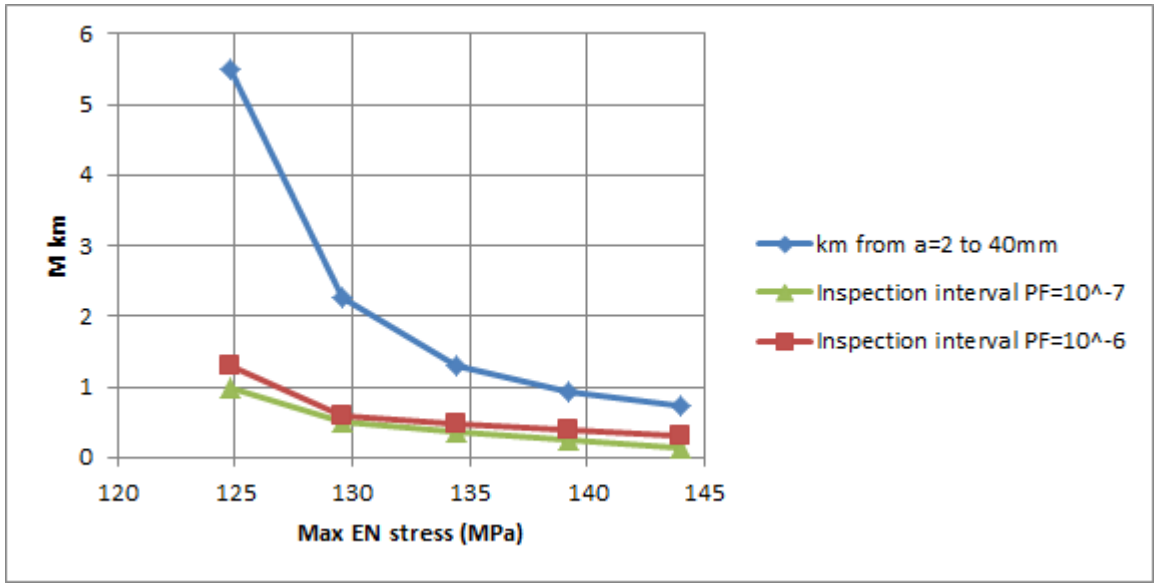
Probability of failure
based on POD at defined intervals

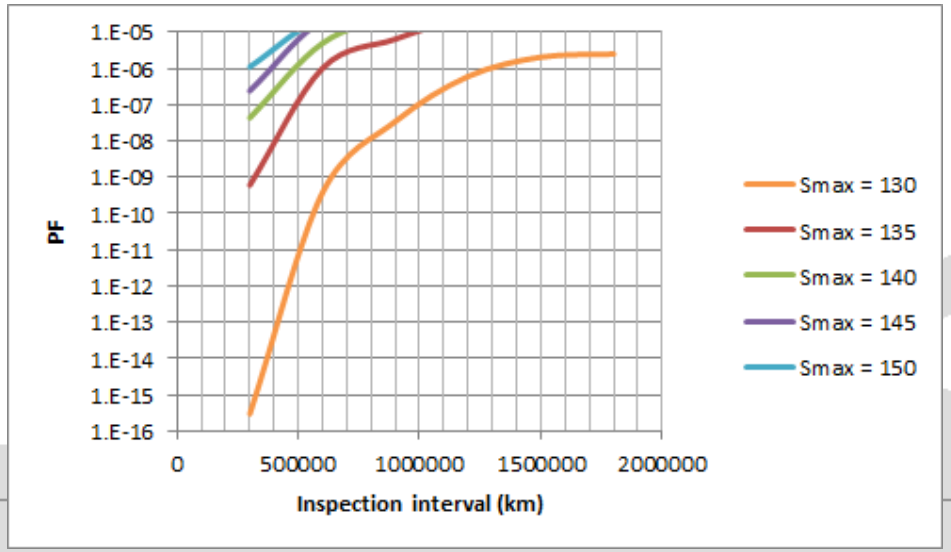




$$PF = \left(\prod_{n} POND_i \right)$$

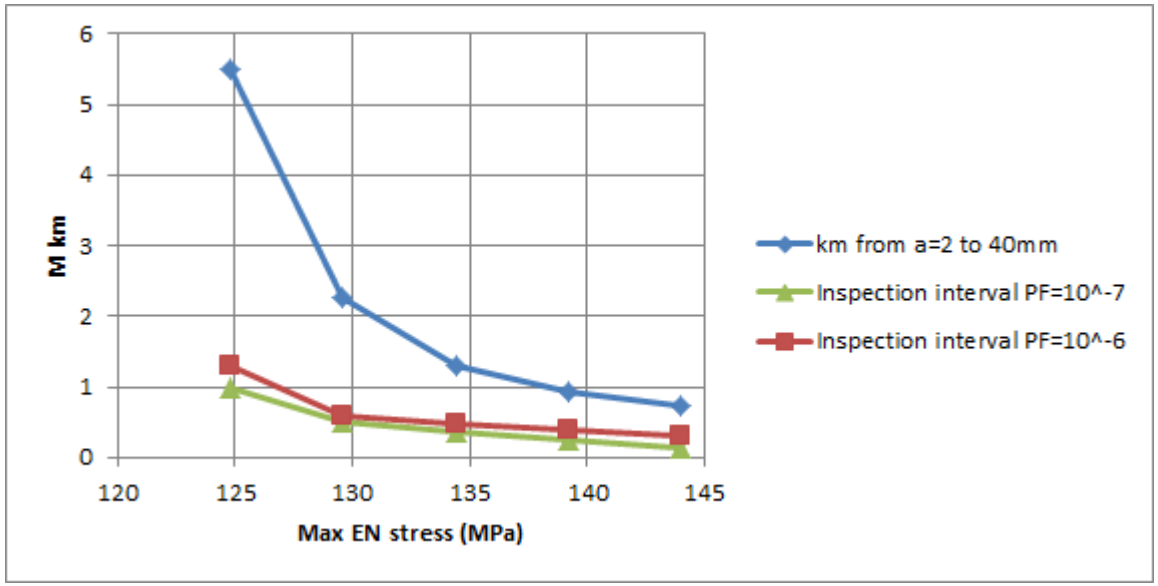
Probability of failure
based on POD at defined intervals





$$PF = \left(\prod_{n} POND_i \right)$$

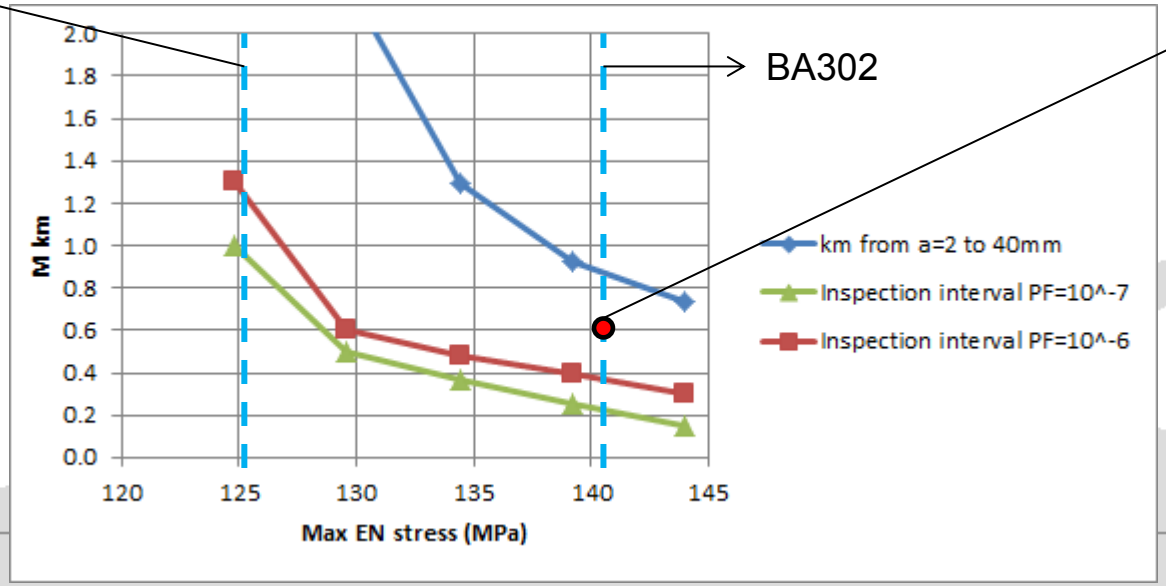
Probability of failure
based on POD at defined intervals



Freiset

BA302

Present inspection interval for MT of BA302 axle.



Conclusions

- A new axle for freight wheelset is designed for axle load up to 25 ton with higher safety factor (EA1N)
- A relatively simple 1:1 scale experimental test is performed to characterize the crack propagation behavior under realistic load spectra (variable loads) and adaptable to different **axle loads** or **axle designs**
- Crack propagation is then calculated for different maximum loads (of the spectra) or according to EN13103
- Example of POD curve for UT near end scan is considered as a periodic inspection and Probability of Failure is calculated for different inspection intervals and different maximum loads
- Finally Inspection intervals are provided for the two reference axles :

	PF 10^-6 (UT near end scan)	**notes**
Freiset axle (125.8 MPa)	1,200,000 km	UT is ok considering better protection from anti impact coating (no MT necessary)
BA302 axle (142.6 MPa)	350,000 km	MT at 600,000 km is an alternative to UT demonstrated by the service experience

Thank you for the attention