POLITECNICO DI MILANO

ESIS TC24 Meeting

1-2 October 2014

Milano, Italy

Evaluation of the effect of axle protection against ballast impacts

M. Carboni, S. Bruni, S. Cervello

Introduction

Axles are designed against the fatigue limit according to:

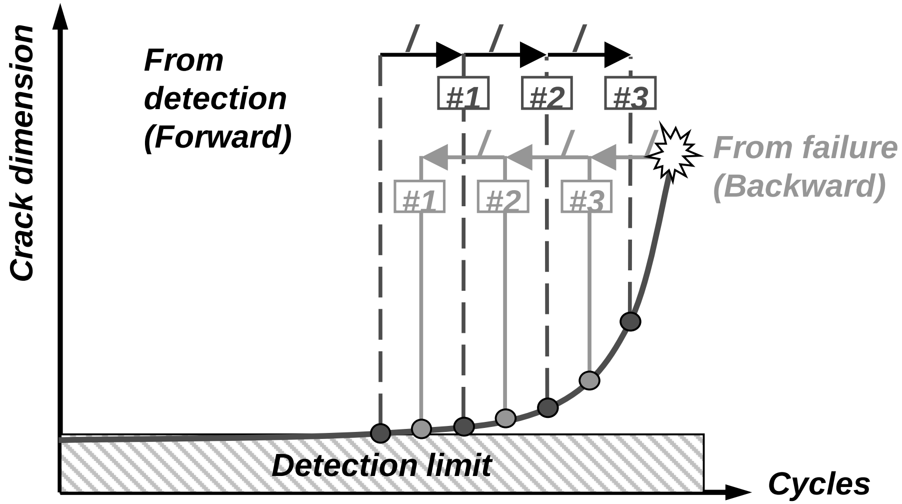
- EN 13261
- EN 13103
- EN 13104

Typical in-service failures due to:

- corrosion-fatigue
- ballast impacts

These phenomena are not included in relevant standards

Damage Tolerance



Introduction

A1N	
Ultimate Strength [MPa]	600
Young's Modulus [GPa]	206
Poisson's Ratio	0.33
Plane Stress Fracture Toughness (K_C) [MPa]	90
Plane Strain Fracture Toughness (K_{IC})[MPa]	52
Yield Strength [MPa]	370

Application

freight axle for Y25 bogie

Proposed solution: LURSAK thick coating

Planned inspection intervals:

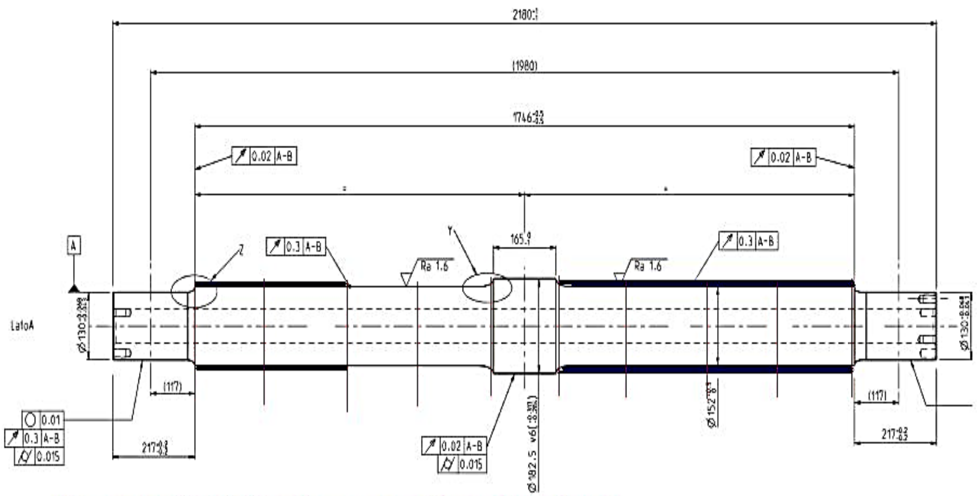
VPI → UT+MT → 12 years or 600.000 km

LURSAK → UT → ?

Outline

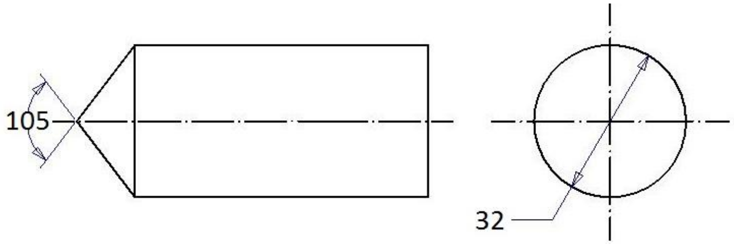
- Experimental impact tests according to EN 13261
- Experimental impact tests using real ballast
- Simulation of crack propagation
- Conclusions

Experimental tests according to EN 13261



Chunks

Weight

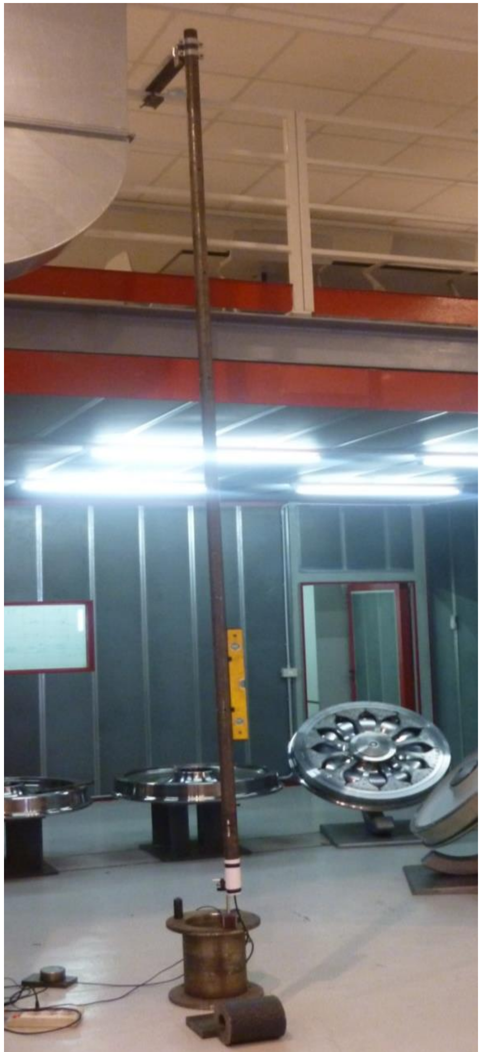


(a) (b) (c)

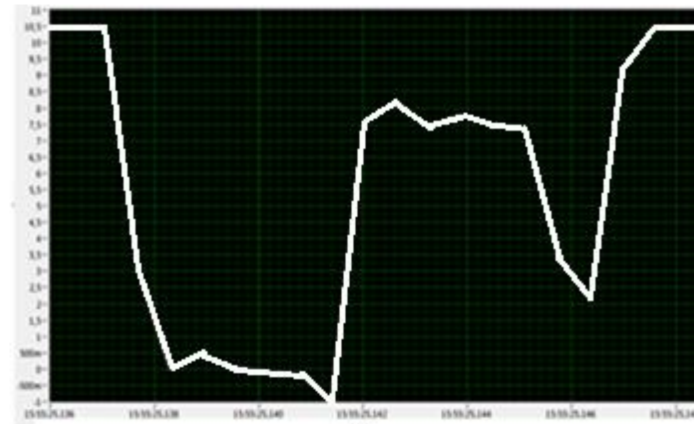
Tip hardness: 400 HV

Experimental tests according to EN 13261

Experimental set-up



Laser



a

b

Laser signal and weight

Experimental tests according to EN 13261

Tests conditions

Axle	Energy 12J	Energy 22J	Energy 32J
Uncoated	x	x	x
Newly coated	x		x
Newly coated at T=-25°C	x		x
Aged coating	x		x
Aged coating at T=-25°C	x		x

Tabella 2.8 Cicli termici per invecchiamento vernice LURSAK

	orario entrata in forno	orario entrata in freezer	ore totali in forno e in freezer
data	T=50°C	T=-5°C	h
20/03/2013	8:30	16:30	8h in forno, 7.30 h freezer
21/03/2013	8:30	16:30	8h in forno, 16 in freezer
22/03/2013	8:30	16:30	8h in forno, 16 in freezer
23/03/2013	-	-	freezer 24h
24/03/2013	-	-	freezer 24h
25/03/2013	8:30	16:30	8h in forno, 16 in freezer
26/03/2013	8:30	16:30	8h in forno, 16 in freezer
27/03/2013	8:30	16:30	8h in forno, 16 in freezer
28/03/2013	8:30	16:30	8h in forno, 16 in freezer
29/03/2013	8:30	16:30	8h in forno, 16 in freezer

- Total time for the aging process: 1 month
- Relevant standard: ASTM D 6944 – 03

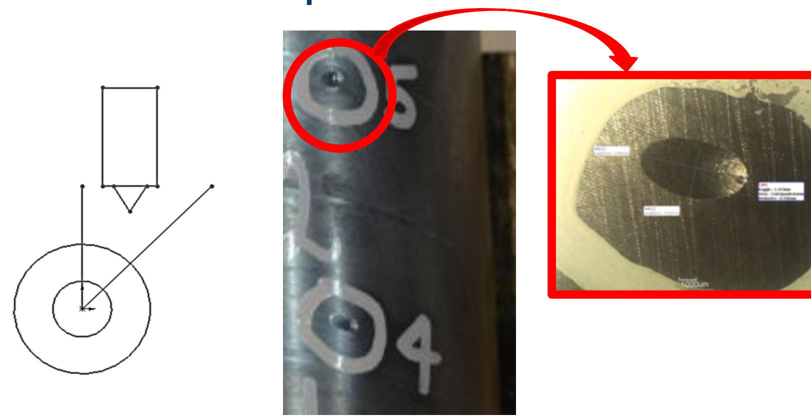
Experimental tests according to EN 13261

Uncoated, E=12 J

Max depth: 0.88 mm

Uncoated, 45° angle, E=12 J

Max depth: 0.2 mm



Uncoated, E=22 J

Max depth: 0.95 mm

Uncoated, E=32 J

Max depth: 1 mm

Uncoated, 45° angle, E=32 J

Max depth: 0.5 mm

Experimental tests according to EN 13261

Newly coated, E=12 J

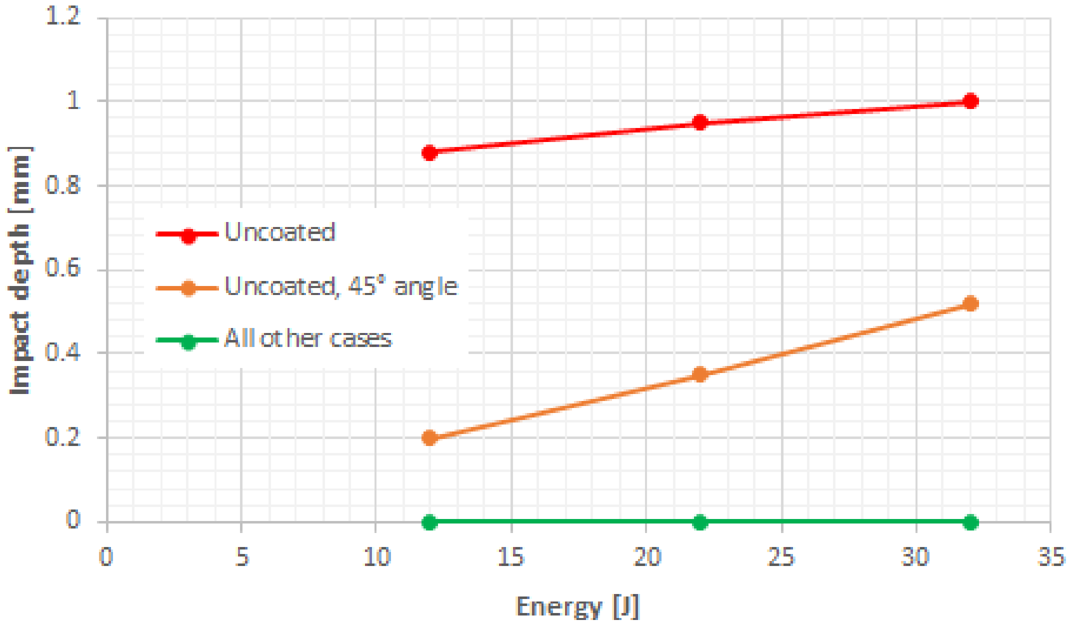
Newly coated, E=32 J

Newly coated, 45° angle E=32 J

Aged coating, E=12 J

Aged coating, E=32 J

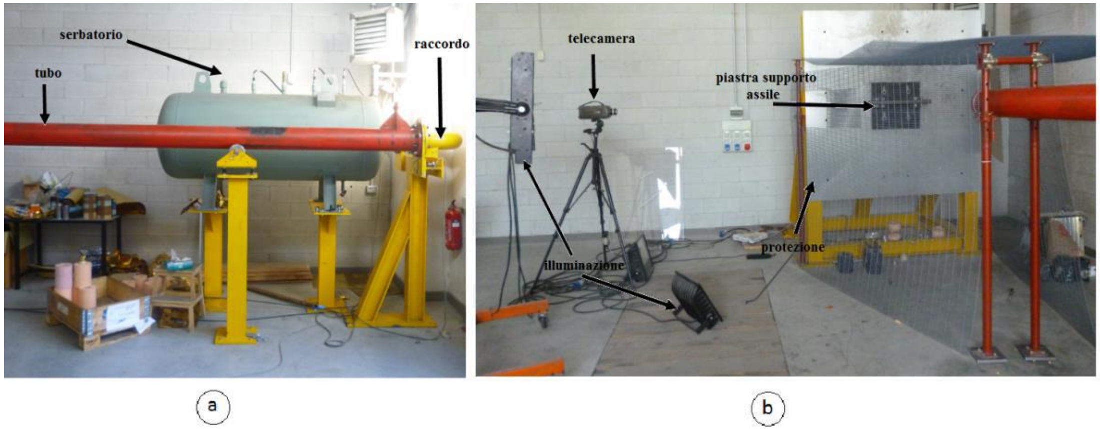
Experimental tests according to EN 13261

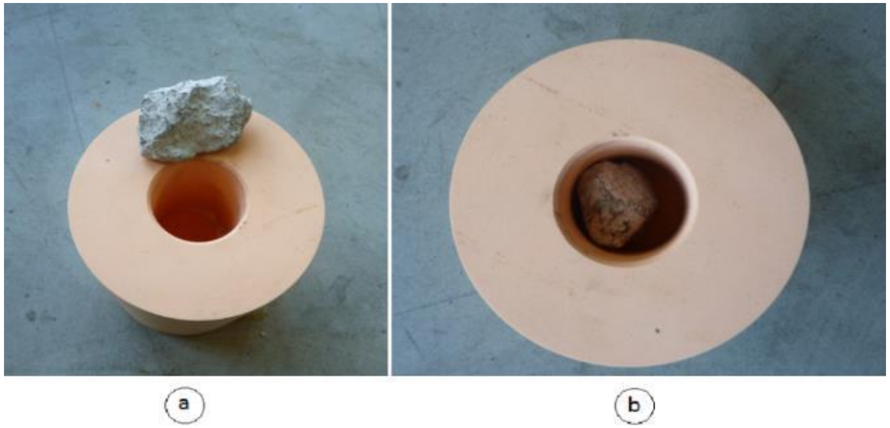


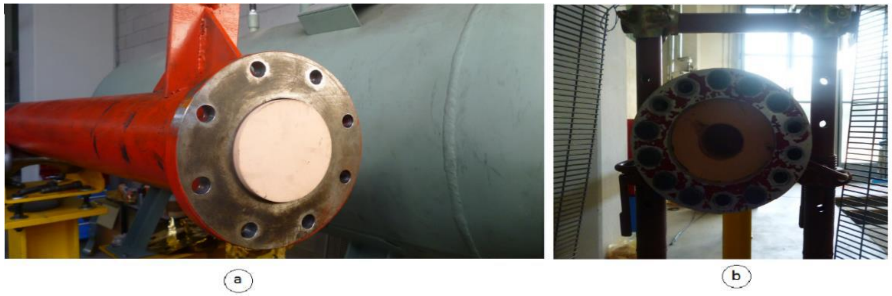
- Even if some cases showed detachment of the coating, no damage of the underlying metal was observed also considering about three times the standard energy
- The uncoated configuration is the most dangerous and a linear correlation between the impact energy and the corresponding damage is highlighted
- The worst damage is achieved by perpendicular impacts

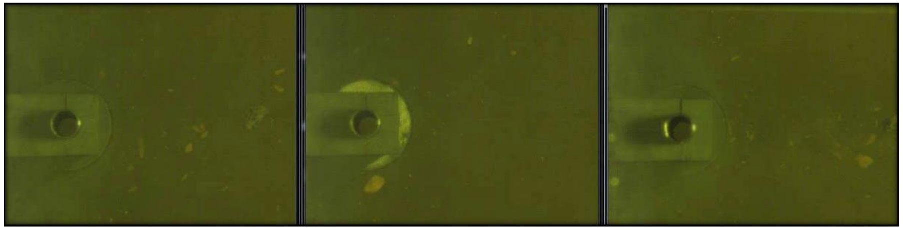
Experimental impact tests using real ballast

The experimental set-up was obtained modifying a “rooster booster” cannon









Experimental impact tests using real ballast

Tests conditions

Low speeds representing freight applications

Axle	Energy [J]	Stone speed [km/h]
Uncoated	68	112.5
Newly coated	280	251.3
Aged coating	225	251.3

High speeds representing high speed applications

Axle	Energy [J]	Stone speed [km/h]
Uncoated	979	411.3
Newly coated	559	363.0
Aged coating	575	385.8

Due to the experimental difficulties, the obtained speeds (and energies) are significantly higher than the real ones for freight and high speed trains

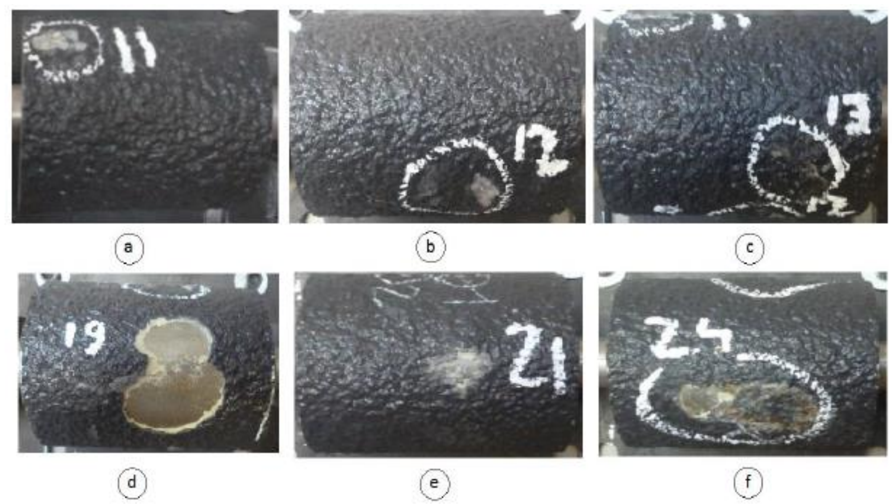
No tests at T=-25°C

Experimental impact tests using real ballast

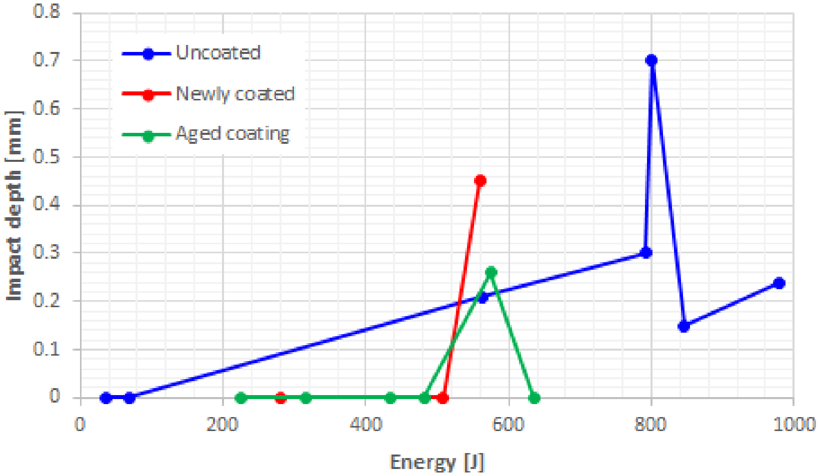
Uncoated

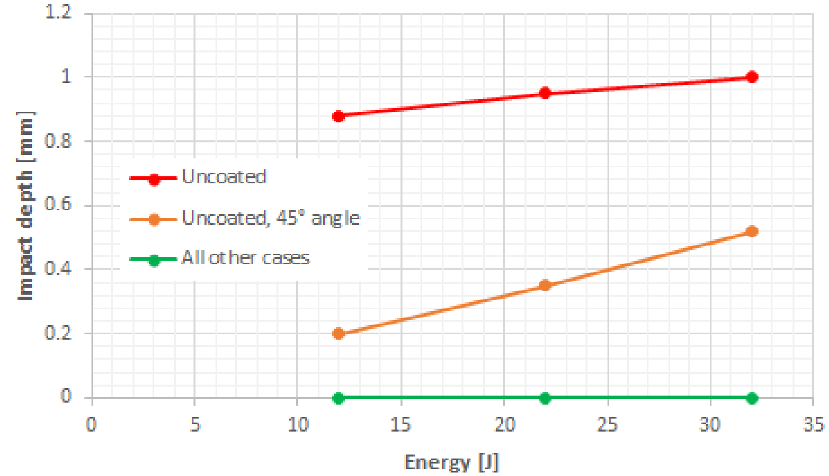
Newly coated

Aged coating



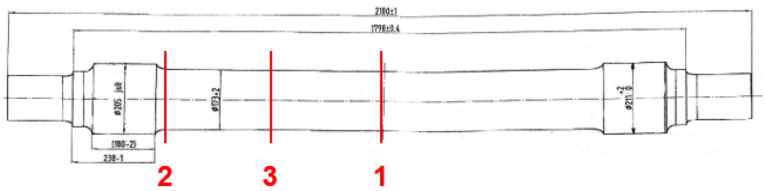
Experimental impact tests using real ballast





- It's really difficult to find out a correlation between the standardized test and the real ballast impacts: is the standardized test significant?
- Ballast impacts were able to damage the metallic material under coating, with a maximum impact depth equal to 0.5 mm: this confirms the too high energies gotten during the tests, because experience on more than 10000 wheel-sets over the last 5 years never showed any damage of the metallic material
- The uncoated configuration reaches the same damage of the standardized test at a very high energy (about 800 J)

Simulation of crack propagation



Semi-circular initial defect in each section:

- $a_i = 2$ mm for uncoated axle
- $a_i = 1$ mm for coated axle

Load spectra obtained by dynamic analyses of the train (tare + full payload)

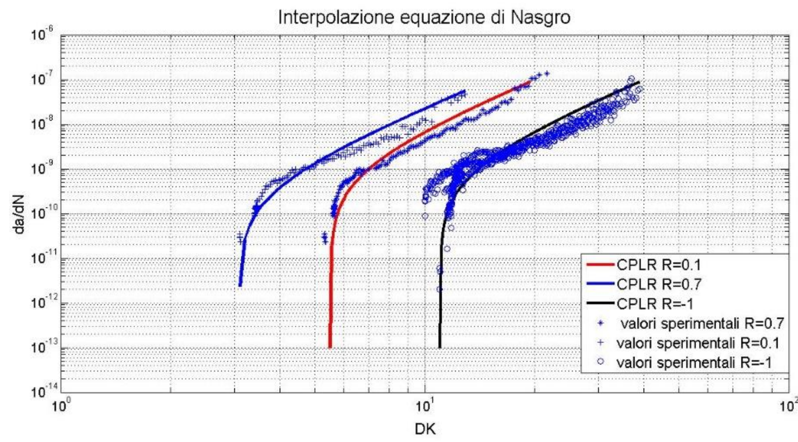
One repetition: 22659 km

Simulation of crack propagation

Crack growth predictions were carried out by AFGrow v. 4.0012.15

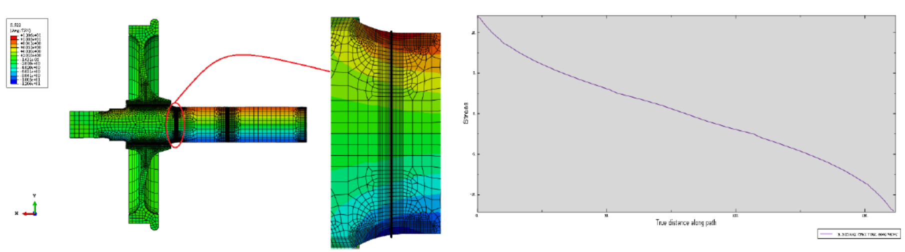
$$\frac{da}{dN} = C \cdot \left[\left(\frac{1-f}{1-R} \right) \cdot \Delta K \right]^m \cdot \frac{\left(1 - \frac{\Delta K_{th}}{\Delta K} \right)^p}{\left(1 - \frac{K_{max}}{K_c} \right)^q}$$

$$\Delta K_{th} = \Delta K_0 \frac{\sqrt{\left(\frac{a}{a+a_0} \right)}}{\left(\frac{1-f}{(1-A_0)(1-R)} \right)^{(1+C_{th}R)}}$$

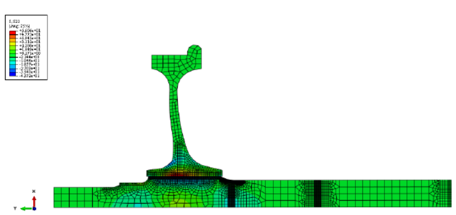


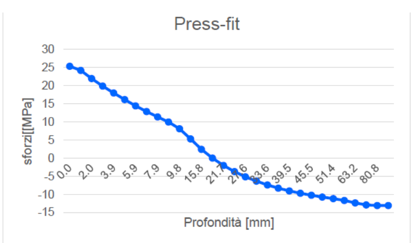
Experimental data were collected adopting compression pre-cracking techniques

Bending



Press-fit (Sec. 2)



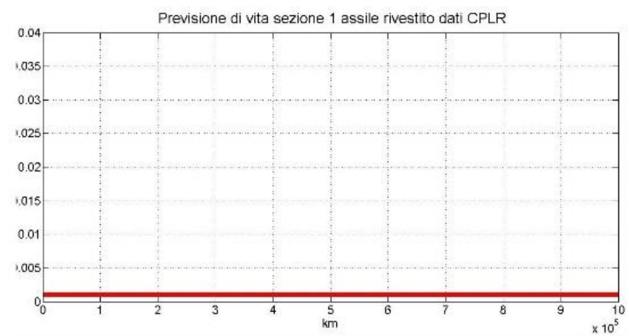


Simulation of crack propagation

	Uncoated	Coated

Section 2

Sections 1 and 3



	UNCOATED		**COATED**	
	a_i = 2 mm		a_i = 1 mm	
	km	a_f [mm]	km	a_f [mm]
SEC. 1	10^7	no propagation	10^7	no propagation
SEC. 2	$6.797x10^6$	30	10^7	no propagation
SEC. 3	10^7	no propagation	10^7	no propagation

For the considered service case, the coated axle never fails within 10^7 km

The uncoated one fails at the T-transition within 10^7 km

Concluding remarks

The effect of thick coating protections against ballast impacts was analysed for A1N axles adopted in Y25 bogies. Results can be summarised:

- experimental tests according to standards showed, in some cases, detachment of the coating, but no damage of the underlying metal
- it's really difficult to find out a correlation between the standardized test and real ballast impacts
- ballast impacts, characterized by energies much higher than the real ones, were able to damage the metallic material below the coating
- damages start to appear for energies representative of high speed applications
- crack growth simulations showed no failure, within 10^7 km, of the coated chunks making the calculation of the probability of failure and the comparison with the uncoated configuration meaningless (at least for the considered applicative case)