A Reliability Study of Phased Array Ultrasonic Inspections Applied to Aluminothermic Welds in Rails

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Abstract

Nowadays, long welded railway rails are manufactured by means of aluminothermic and flush-butt welding processes. Compared to bolted joints, welds proved to be effective in terms of reduced wheel damage, ride comfort and maintenance. However, even if the event is inexplicably not considered in relevant standards, surface cracks often initiate within the welded and the heat affected regions of the foot, leading to brittle failure. On the subject, a recent work developed a probabilistic methodology for determining day-by-day failure probability. However, apart from this structural integrity study and few others, a complete damage tolerance approach should also consider the capability of nondestructive inspections. The latter is recognized as an essential input to define maintenance inspection intervals. The present work is focused on the capability assessment of Phased Array ultrasonic inspection applied to aluminothermic-welded joints by means of Probability of Detection curves, as a result of experimental and Model Assisted data samples.

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Michele CARBONI, Andrea GIANNEO

Introduction


Long welded rail → Substitutes traditional bolted joints


Semi-elliptical fatigue cracks can initiate at the foot base (due to defects and/or stress concentration) causing rail failure

EN 14730 → Periodic maintenance NDT inspections by **conventional** ultrasonic testing only considering centred cracks inspected from the rolling surface

The right approach, then, requires **optimized** inspection intervals defined by the application of the "**Damage Tolerance**" concept, which implies the availability, along with other "ingredients", of **reliable POD curves** for the adopted UT technique

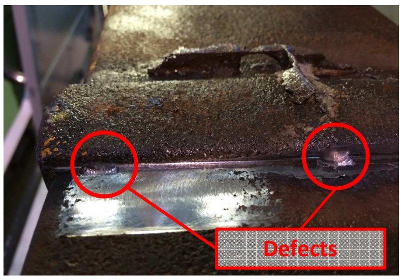
Aims of the research work

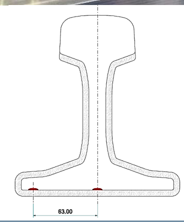
The present research proposes to substitute the conventional UT approach with **Phased Array Ultrasonic Testing** (PAUT), as already done by FERROVIENORD in Italy, and tries to evaluate its reliability for aluminothermic welded rails

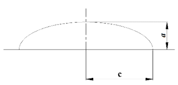
1. Experimental evaluation of PAUT responses from reference defects
2. Optimization of the PAUT inspection procedure
3. Numerical modelling and definition of MAPOD curves

Experiments

Artificial semi-elliptical notches were introduced into two sample welded rails (R260, type 60E1)

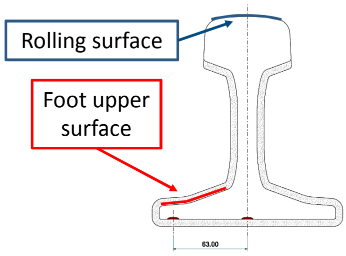






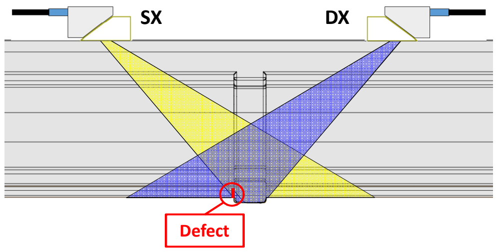
- at the symmetry axis and at the tip of he foot
- depth from 0.5 mm to 2 mm (five steps in between)
- aspect ratio (a/c) = 0.4
- manufacturing by milling (spherical tip) and progressive increase of size between inspections

Experiments



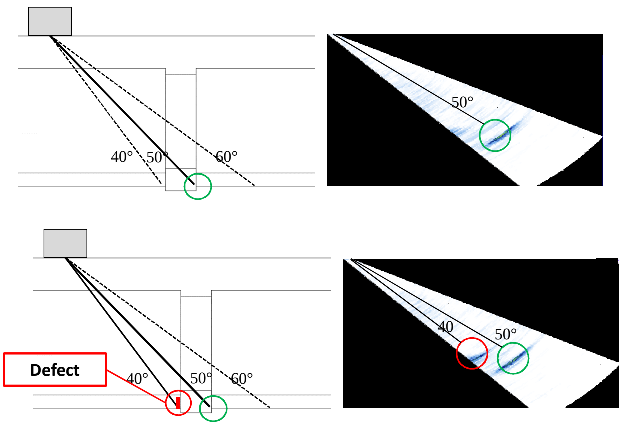
Approach:

- SX: defect side
- DX: through the weld and heat affected zones

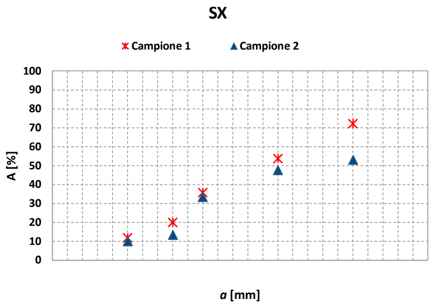


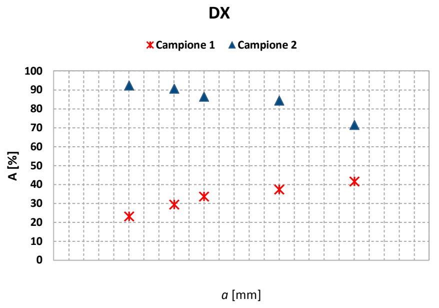
Experimental results – Rolling surface

- Olympus Omniscan
- S-Scan 40°- 60°
- Linear probe 2L64-A2 (2.25 MHz, 64 elements)



Experimental results – Rolling surface



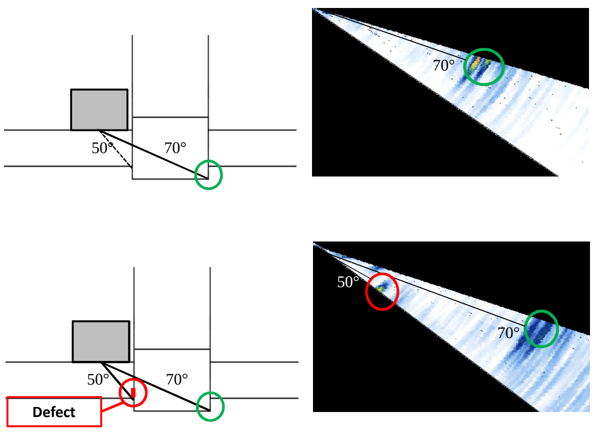


The DX approach (sound beam through weld and heat affected zones) is not acceptable and not consistent. The reason is ascribed to the microstructure

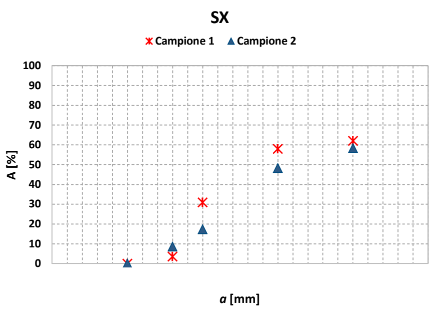
Inspections should be carried out from both sides of the weld

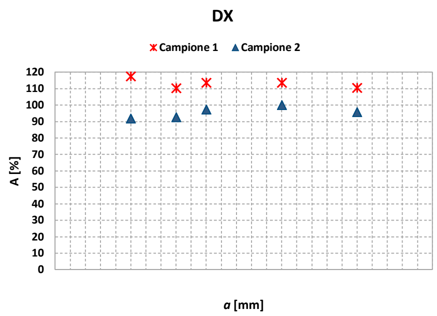
Experimental results – Foot upper surface

- Olympus Omniscan
- S-Scan 50°- 70°
- Linear probe 2L8-DGS1 (2.25 MHz, 8 elements)



Experimental results – Foot upper surface





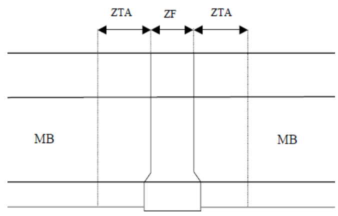
The same conclusions observed for the inspection from the rolling surface can be drawn

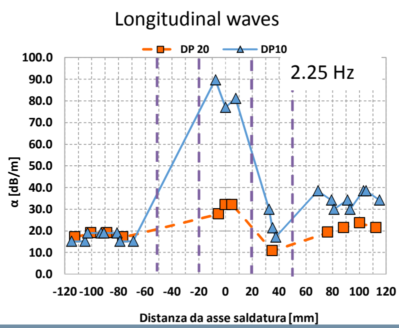
Structural attenuation – Experimental characterization

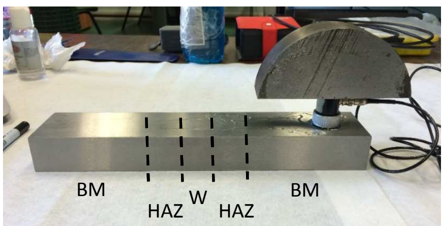
A careful characterization of the structural attenuation is needed for a **better numerical modelling** of PAUT inspections

Structural attenuation **can explain** the inconsistent behaviour of the DX approach, as well

Both longitudinal and shear waves were characterized

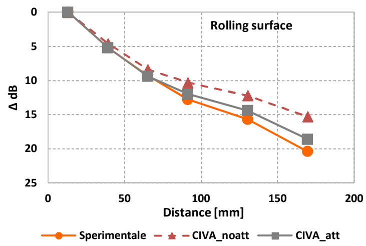


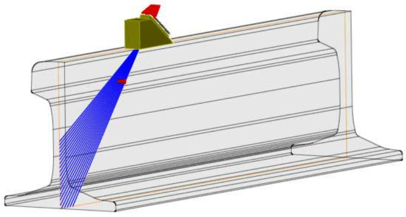


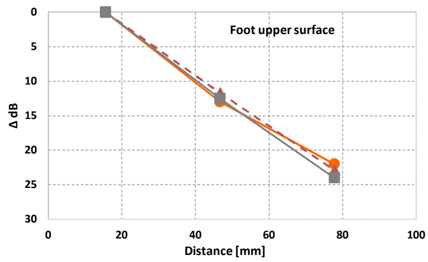


Calibration of the numerical model

- CIVA^{nde} 11.0
- The real calibration procedure used for in-service inspections was modelled: 2 rails with a total of 6 SDH (diameter = 5mm)
- The response is obtained in terms of dBs needed to get 80% screen height
- The sensitivity to structural attenuation was checked

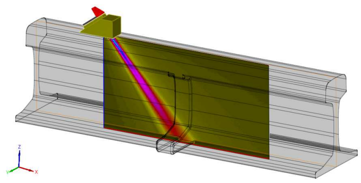


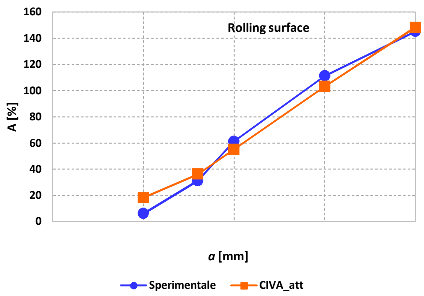


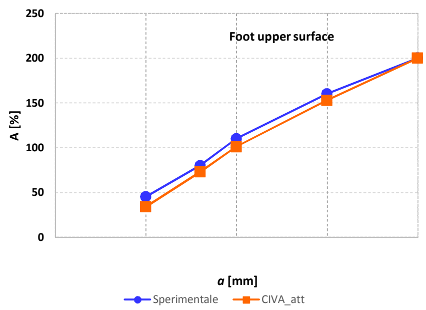


Validation of the numerical model

The validation of the numerical model was carried out by simulating all of the SX experimental trials



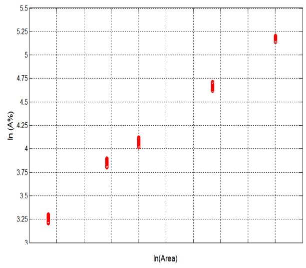


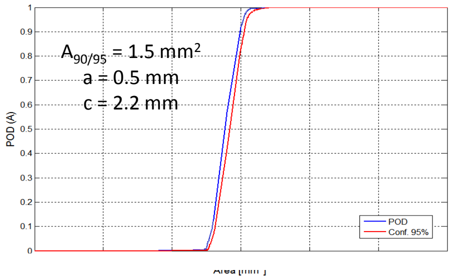


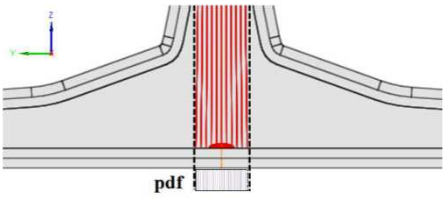
MAPOD curves

Rolling surface

- Montecarlo simulations
- Two varying parameters: crack size and its position in the foot
- 29 extractions for each crack size
- PAUT response in terms of reflecting area
- Noise: 6%
- Saturation: 200%
- $\hat{a}_{th}$ = 20%



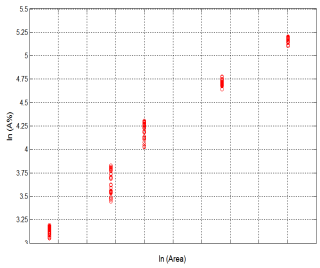


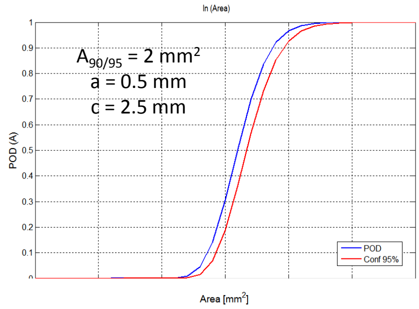


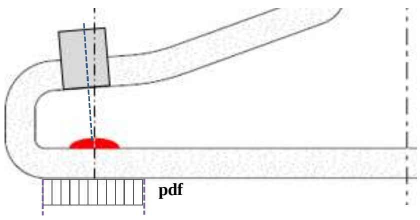
MAPOD curves

Foot upper surface

- Montecarlo simulations
- Two varying parameters: crack size and its position in the foot
- 29 extractions for each crack size
- PAUT response in terms of reflecting area
- Noise: 6%
- Saturation: 200%
- $\hat{a}_{th}$ = 20%







Concluding remarks

- ☑ Application of PAUT instead of conventional UT
- ☑ inspection procedure for the foot
- ☑ Determination of MAPOD curves
- ☑ Possibility to re-design the inspection intervals

Future developments

- To consider more stochastic parameters in numerical analyses
- Comparison to conventional UT
- To carry out more experimental trials considering different defect shapes and locations
- Inspections from the foot upper surface must be improved