Determination of Inspection intervals for welded rail joints on a regional network

S. Romano, S. Beretta[1]
S. Galli, R. Riccardo [2]
stefano.beretta@polimi.it

1- POLItecnico di MIlano, Dept. Mechanical Engineering, Milan, Italy
2 - FerrovieNord, Milan, Italy

ESIS TC24 Meeting Leoben

POLITECNICO
MILANO 1863

Introduction
- The research
- Aluminothermic weld failures

Life propagation model
- The scheme
- Material characterization
- Integrity assessment
- Semi-probabilistic approach

Applications
- Case histories
- Application to a regional network

The research project

The **general steps** of our research project can be summarised in the following points:

1. how to describe the structural integrity of a rail welded joint;
2. how to consider the *probabilistic aspects* in a simple yet affordable way;
3. to draw general conclusions by applying the approach to a regional network characterized by a large variety of tonnage for the different sections.

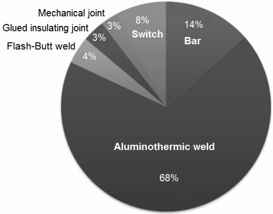
In this presentation I'm going to summarize the results for the first two steps and I will especially address the third topic.

Results about the method have published in:

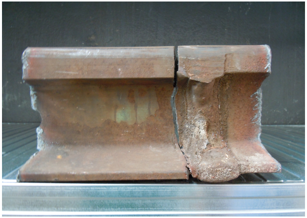
Romano, S., Manenti, D., Beretta, S., Zerbst, U. (2016) Semi-probabilistic method for residual lifetime of aluminothermic welded rails with foot cracks *Theoretical and Applied Fracture Mechanics*, vol. 85, pp. 398-411.

Importance of the analysis for aluminothermic welds

Aluminothermic welds are very common in railway lines, but they represent also the **the main failure mode** for the rails:

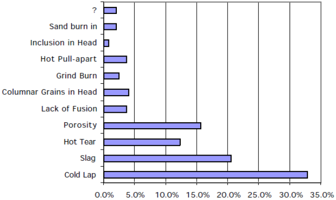


(a) Statistics of rail failures



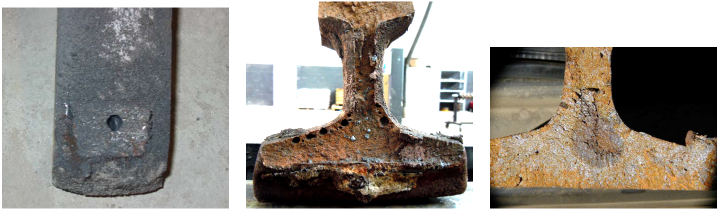
(b) An example of vertical failure

- here we consider vertical failures, that are not critical for safety but rather for network availability;
- if we refer to failures of the aluminothermic welds, they are caused by a significant number defects;



(c) origin of aluminothermic failures

Typical problems for aluminothermic welds



(c) Black hole [1]. (d) Porosity. (e) Shrinkage [1].

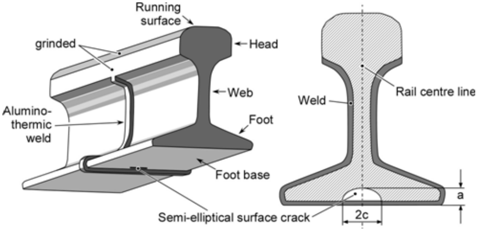
(f) Cold lap [2]. (g) Sandburns [1].

Figure: Typical defects in aluminothermic welds

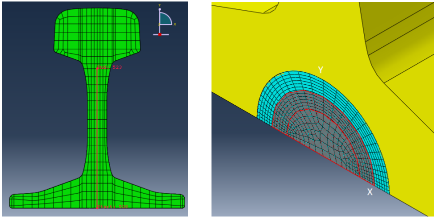
Schematics of the problem (1 of 3)

The idea for the integrity assessment of the welded joint is to imagine a prospective crack at the rail foot and located near the weld toe.

A good approximation is to adopt a simplified geometry for a plate with the same height as the rail section.



(a) schematics of the problem

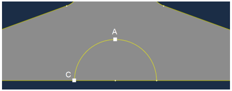


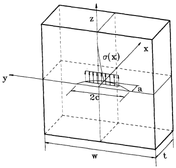
(b) model of the rail (c) sub-model of the crack

Figure: Modelling of cracks at the rail foot

Schematics of the problem (2 of 3)

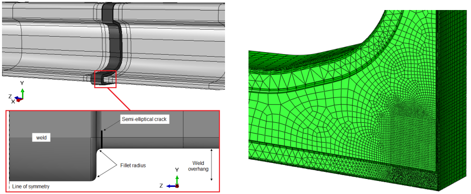
The SIF for a crack at the weld toe has been modelled with the same substitute geometry but considering the real state of stress at the weld toe and the WF solution by Wang & Lambert.





the comparison between WF and FE solutions showed a maximum error of 20% for cracks with $a > 2mm$ and $0.4 < a/c < 1$.

(a) comparison between model and real geometry



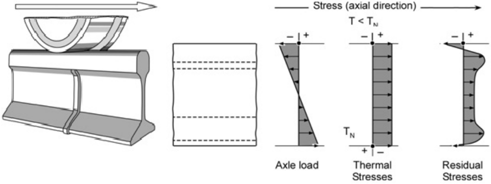
(b) 3D model of weld geometry

(c) dense mesh in the crack region

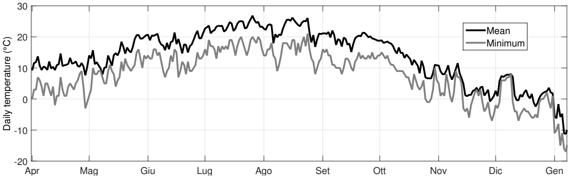
Figure: Modelling of cracks at the weld toe

Schematics of the problem (3 of 3)

The different loads acting on the rail weld are:



(a) stress types on the weld (T_N = neutral temperature)

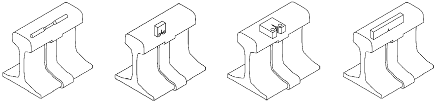


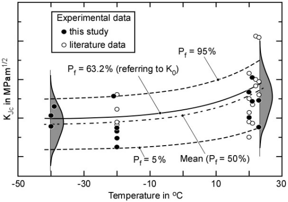
(b) daily max/min temperatures measured in Saronno (near Milan)

$$K = K_{axle\ load} + K_{thermal\ stress} + K_{residual\ stress}$$

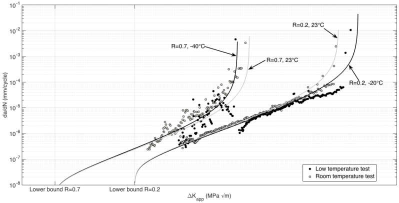
Material charaterization

The weld material has been characterized by a seried of tests for determining: a) tensile properties; ii) fracture toughness and crack growth rate.





(c) Master curve for fracture toughness



(d) crack growth rate at different temperatures

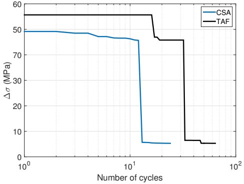
in winter service conditions the welds are in the **"lower shelf"** !

Integrity assessment of aluminothermic weld (1 of 2)

The integrity analysis has been done considering the real service conditions of a regional network (Ferrovie Nord) in the Lombardia region.
The traffic is characterized by two types of trains. firstly the analysis has considered *quasi-static* loads.

(e) TAF train (8 coaches, capacity 1800 kg)

(f) CSA train (4 coaches, capacity 500 kg)



(g) quasi-static bending stress spectra

Assumptions for the analysis:

- initial crack size $a_o = 0.9\,[mm]$ ($EFBH = 2\,[mm]$);
- crack propagation with $a/c = 0.4$ (which is the stabilized shape).

Integrity assessment of aluminothermic weld (2 of 2)

The assessment against fracture is based on elasto-plastic *driving force* according to BS7910 format:

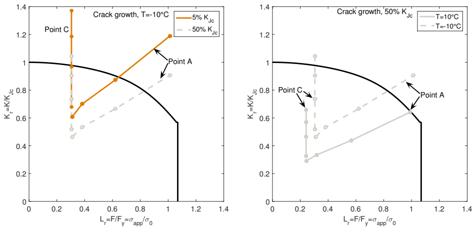
$$K_J = \frac{K}{f(L_r)} \leq K_{JC}$$

that leads to the FAD diagram:

$$\frac{K}{K_{JC}} \leq f(L_r)$$

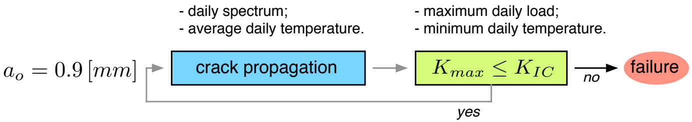
where $L_r = \sigma/\sigma_Y$

Example calculation under 50 TAFs per day:



(h) influence of K_{JC} (i) influence of T

The scheme for the assessment is to follow the day-by-day crack propagation and to evaluate its potential failure as:



- daily spectrum;
- average daily temperature.

- maximum daily load;
- minimum daily temperature.

$a_o = 0.9\,[mm]$

crack propagation

$K_{max} \leq K_{IC}$

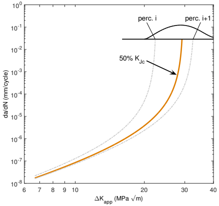
no

failure

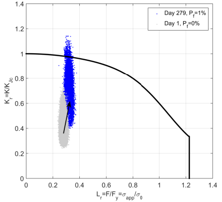
yes

Semi-probabilistic approach

There is the need for a probabilistic approach, since the scatter of K_{JC} affects also the crack propagation rate. If we do the analysis with a Montecarlo simulation:



(j) random extraction for K_{JC}

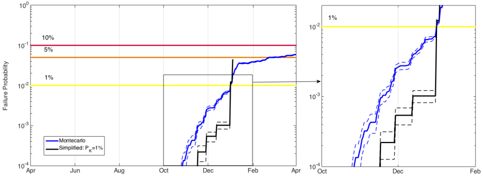


(k) evolution on FAD

A simplified calculation scheme:

- day-by-day propagation is calculated with 1% $P_{K_{JC}}$;
- failure probability under maximum load is fully probabilistic.

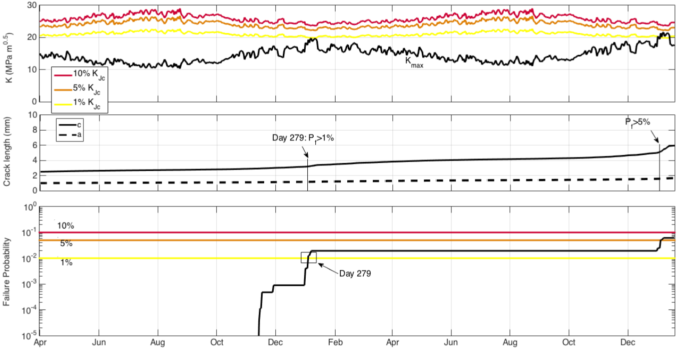
The Monte Carlo simulation for 10^6 extractions has shown that the two approaches calculate the same result for $P_f \geq 1\%$



Comparison between full Monte Carlo and simplified approach (10^6 extractions)

Case histories (1 of 3)

If we consider a given daily spectrum (50 TAFs) it is easy to see the *safety margin* by simply plotting the day-by-day K_{max} and to compare it with K_{JC}.

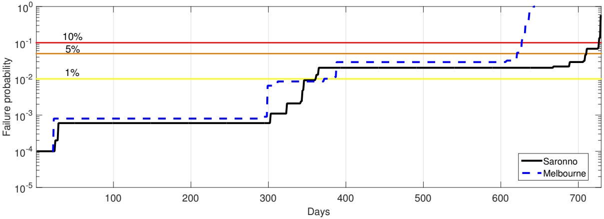


Simulation of the propagation after a prospective inspection in April
(50 TAFs per day, $a_o = 0.9\,[mm]$, $a_o/c_0 = 0.4$)

Case histories (2 of 3)

It looks that the relevant parameter is the minimum temperature, but in reality it is the difference ($T_N - T_{min)}$ (neutral temperature - minimum temperature). We have verified this guess by choosing a city with the same yearly excursion as Saronno.

City	T_N	ΔT_{max} (^{o}C)	T_{min} (^{o}C)	T_{max} (^{o}C)
Saronno	33	42	-9 : 20	2 : 33
Melbourne	41	43	-1 : 27	10 : 42

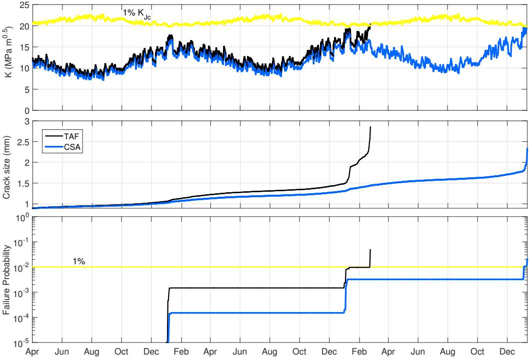


Simulation of the propagation after a prospective inspection in April (50 TAFs per day, $a_o = 0.9\,[mm]$, $a_o/c_0 = 0.4$)

Case histories (3 of 3)

We have considered a propagation lifetime for the same daily tonnage, but obtained with different trains.

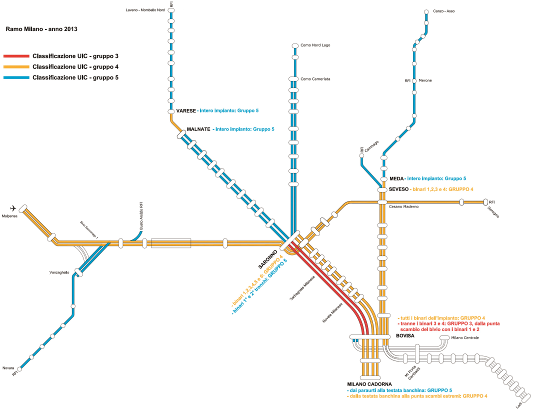
Train type	Train mass (t)	Trains per day	Line daily tonnage (t)
TAF	1.81	50	90.6
CSA	0.51	179	90.6



Simulation of the propagation after a prospective inspection in April for two different train types ($a_o = 0.9\,[mm]$, $a_o/c_0 = 0.4$)

Application to a regional network (1 of 3)

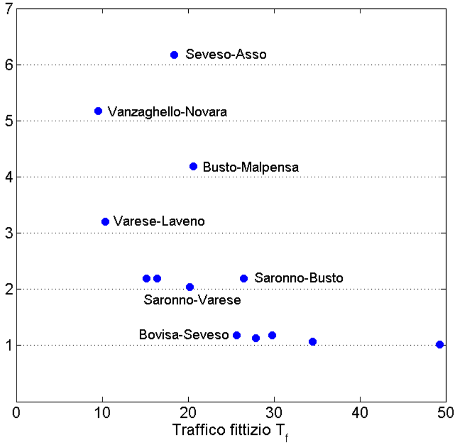
The analysis tool has been adopted for predicting the propagation lifetime onto the regional network of Ferrovie Nord Milano (FNM), which is characterised by trunks with a variety of tonnages.



Network examined

Application to a regional network (2 of 3)

The results show that, even if the lines have the same classification according to `UIC714R` [3], the propagation lifetime is very different.

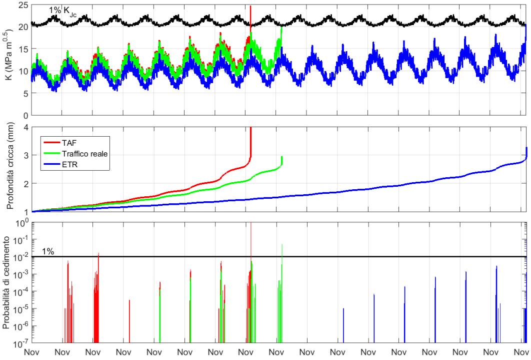


Propagation lifetime vs. daily tonnage

Application to a regional network (3 of 3)

The reason for this discrepancy is that K_{max} plays a significant role, since we are in the lower shelf region, while `UIC714R` implicitly refers to ΔK as it was *usual fatigue*.

This is confirmed by doing the simulations, for a given line, for different stress spectra that refers to the same tonnage.



Propagation lifetime for the same line
(Saronno-Busto line with real traffic and two different trains)

Conclusions

In this research we have set-up a structural integrity model for the propagation lifetime of cracks at the weld toe of aluminothermic rail weld.

The conclusions that we can draw are:

- a propagation model should consider the different loads acting on the weld;
- below $0^o\ C$ the fracture toughness of welds is in the *lower shelf* with a significant scatter;
- variability of the toughness implies also a significant variability of the growth rate when $K_{max} \rightarrow K_{JC}$;
- estimation of propagation lifetime needs a semi-probabilistic approach;
- results show that K_{max} (and the maximum load) plays a significant role in determining the propagation lifetime;
- this fact prevents the application of a simple concept such as the *tonnage* of `UIC714R`.

References

Welding Technolody Institute of Australia.
Aluminothermic Weld Defects, 2006.

I. Salehi, A. Kapoor, and P. Mutton.
Multi-axial fatigue analysis of aluminothermic rail welds under high axle load condition.
International Journal of Fatigue, 33, 2011.

UIC 714R.
Classification des voies des lignes au point de vue de la maintenance de la voie.
Technical report, 2009.