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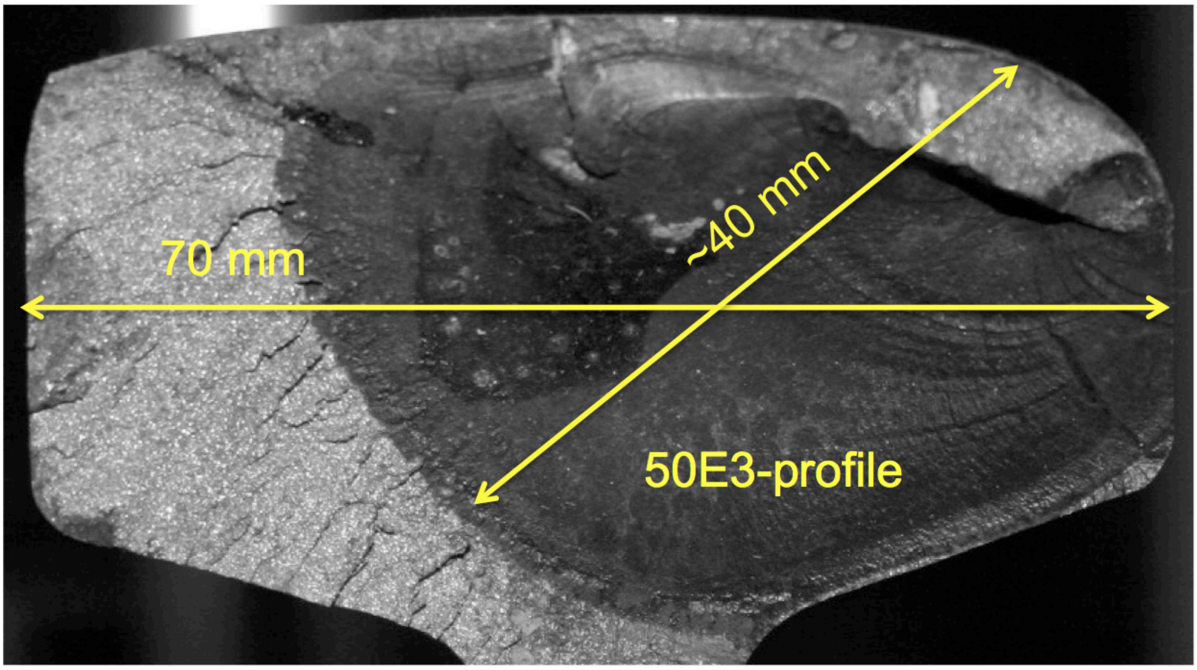

Research report 2014:05

Surface fatigue initiated transverse defects and broken rails – an International Review

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Abstract

The current report briefly compares some operational experience of cracked and broken rails from China, Russia, South Africa, Sweden, UK and USA. Four key questions are addressed:

1. Is the critical crack length, i.e. the length of a surface initiated crack that causes a rail break (reasonably) constant in an international perspective?
2. Is it (reasonably) constant over a line?
3. Can the depth when a rolling contact fatigue crack deviates to a transverse propagation be estimated?
4. Is it (reasonably) constant in an international perspective?

The answers can briefly be summarized as

1. No. Deviations in crack sizes from roughly 10% up to roughly 80% of the railhead area at fracture have been found.
2. Not generally, but for some lines this seems to be the case if fractures at the same season are considered (i.e. climate effects are excluded).
3. There are indications that this depth is in the order of 5 mm with a fair amount of scatter. However it is very difficult to identify from a photo whether an area of the fracture surface actually corresponds to inclined fatigue crack propagation.
4. With a reservation in the considerable scatter, there seems to be some consistency also in an international perspective.

Details on how these conclusions were reached are given in the report.

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Introduction

The current report summarizes the results of a project initiated by the International Collaborative Research Initiative (ICRI) on rolling contact fatigue and wear of rail/wheel systems. The aim of the project was to establish whether the critical crack length corresponding to a transversal rail break was reasonably constant in an international perspective. In addition it was also investigated whether the crack length corresponding to a deviation from inclined to transversal growth was constant.

The investigation is based on failure data from around the world as detailed below.

China – general overview

Data courtesy Xin Zhao, Southwest Jiaotong University, Chengdu

The fracture surfaces found in different books *etc* revealed fatigue crack sizes at fracture of roughly 10% to 80% of the rail head (rail breaks measured on screen featured 10%, 25%, 40%, 70%, 80%).

For cases where any statement is made, RCF cracks are said to propagate to a depth of roughly 6–8 mm before deviating to transverse cracking.

China – case study

Data and picture courtesy Zhou Qingyue CARS

Rail grade	980MPa
Rail section	China 60kg/m, as-rolled rail
Service environment	Passenger and freight, 21t–23t axle load, **a**) 64–67Mt·km/km/year **b**) 70Mt·km/km/year **c**) 79 Mt· km/km/year
Track curvature	**a**) *R* = 600m **b**) *R* = 1000 m **c**) *R* = 800 m
At a stress concentrator	No
Depth at downward deviation	**a**) max 8–15mm **b**) – **c**) –
Type of ties and fasteners	Type Ⅲ Fasteners
Geographical location	Severe curves of mountainous railway

Figure 1 Rail damage corresponding to the cases reported above **a**) shelling caused by incorrect super-elevation causing cant excess; **b**) shelling caused by excessive lubrication in order to reduce the lateral wear **c**) head checks and shelling caused by the use of as-rolled rail, which is not a suitable choice for the current conditions.

Comments

The cracks presented have not formed complete rail breaks. It is therefore difficult to assess the critical crack size. However judging from Figure 1b, the critical crack size should be larger than some 10% of the railhead area.

Russia – general overview

Data and picture courtesy Sergey Zakharov (VNIIZHT)

No detailed failure analyses are available from Russia. However the data in Table 1, compiled by Sergey Zakharov, outlines the number of transverse fatigue cracks and resulting rail breaks.

Table 1 Distribution (in %) of rails removed from track on the Russian Railways [1]

Defect type	Relative number of rail defects (%) by years			
	1980	**1990**	**2000**	**2010**
Transverse fatigue cracks in rail head	21.7	22.1	16.2	13.8
Broken rails (transverse)	0.2	0.2	0.1	0.1

An example of a transverse crack is given in Figure 2. Other examples (photos) of transverse cracks in broken rails were given in [2].

Figure 2 Example of transverse fatigue crack of the railhead. Rail removed from single track [1].

Transverse fatigue crack sizes on the Russian railways are presented in Table 2.

Table 2 Distribution of transverse fatigue crack sizes in 59 studied broken rails [1]

Crack size, mm	Number of rails
8	2
15	23
25	21
35	11
47	2

The influence of climatic conditions on rail breaks for the Russian Railways is presented in Figure 3 (from [1]). It is seen that rail breaks are up to 8 times more likely during winter than during summer.

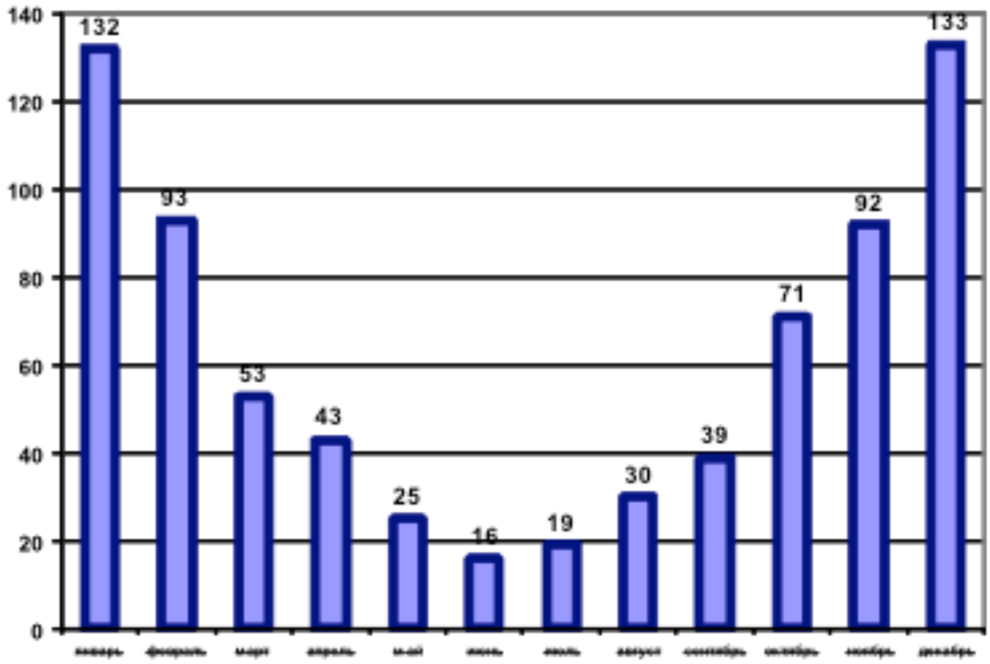


Figure 3 Example of transverse fatigue crack of the railhead. Rail removed from single track [1].

References

1. E. A. Shur. Rail Defects, Moscow, Intext, 2012, 192 pp. (in Russian)
2. S. Zakharov. Wheel and rail performance. In Guidelines to Best Practices for Heavy Haul Operations: Wheel and Rail Interface Issues. IHHA, 2001.

South Africa – case study

Data and picture courtesy Robert Fröhling, Transnet

Rail grade	**a**) Thyssen Head Hardened (7 years in service) **b**) CrMn (In service since 1986)
Rail section	UIC60
Service environment	Freight at 26 ton axle load
Track Curvature	**a**) 604 m **b**) 804 m
At a stress concentrator	Longitudinal sub-surface defect 3 mm below the gauge corner
Depth at downward deviation	**a**) roughly 6 mm* **b**) roughly 7 mm*
Crack size at fracture	**a**) 80% Detail Fracture **c**) 60% Detail Fracture
Geographical location	**a**) Between Lejanedrif and Engogweni on the Coal Export Line **b**) Between Mkondo and Confidence on the Coal Export Line
Time of year	April 2004

* In the figures the upper "deteriorated" region is taken as initiation before deviating into a transversal direction. Note that this region need not correspond to inclined propagation. The data summary states that the deviation depth is not clear.

Comments

The two fracture surfaces (both resulting in rail breaks) are fairly similar in appearance. At final fracture the crack basically extends close to, or into the web. It can be noted that for both cases the propagation in the rail head was slightly inclined (not shown in the pictures below).

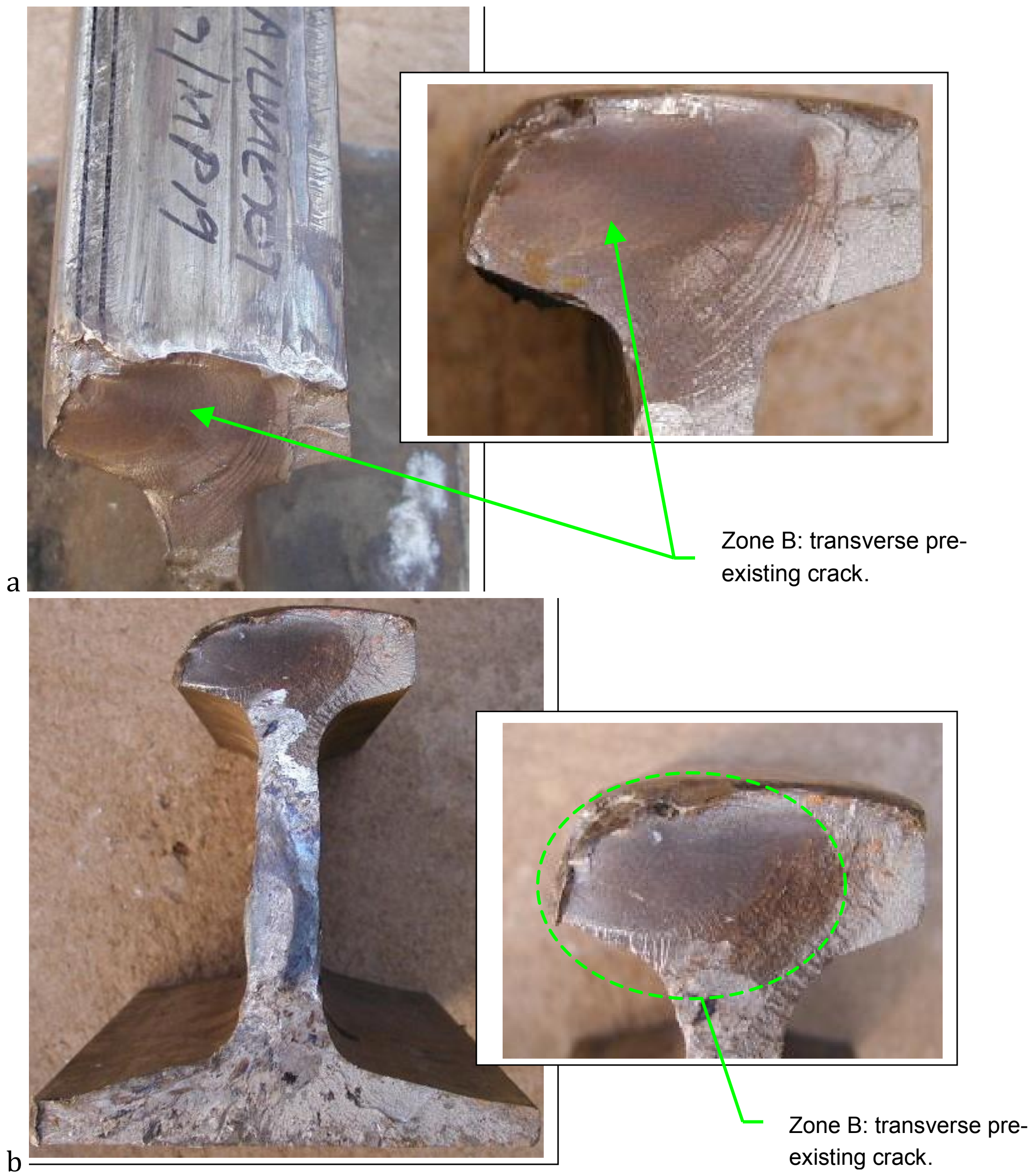


Figure 4 **a**) Rail fracture between Lejanedrif and Engogweni,
b) Rail fracture between Mkondo and Confidence.

Sweden – case study

Data and pictures from the report "Head checks (UIC 2223) och rälsbrott, undersökning av räler från Malmbanan, bdl 111, 2006" by Tamara Gronowicz, Banverket, 2007 (Id F07-2726/BA40).

The report covers laboratory investigations of six operational rails, five of which resulted in rail breaks

Rail grade ....**a**) R350HT
b) 1100
c) not known
d) not known
e) 1100
f) not known

Rail section ....**a**) BV50 (50 kg/m rail)
b) BV50
c) BV50
d) BV50
e) BV50
f) BV50

Service environment ....**a**) Heavy haul
b) Heavy haul
c) Heavy haul
d) Heavy haul
e) Heavy haul
f) Heavy haul

Track curvature ....**a**) not known
b) not known
c) not known
d) not known
e) not known
f) not known

At a stress concentrator ....**a**) No
b) No, close to one sleeper.
c) No, in mid span
d) Partly: mid span 0.45 m from a thermite weld
e) No, close to one sleeper
f) No, mid span

Depth at downward deviation......**a**) No rail break. The cracks had not deviated downwards at a depth of 2mm.
b) Probably ~2 mm
c) Subsurface initiation ~3mm below rail surface*
d) Subsurface initiation 3 mm below rail surface*
e) Subsurface initiation 6 mm below rail surface*

f) Subsurface initiation 5 mm below rail surface*

Crack size at fracture ....a) No final fracture
b) >50 % Detail Fracture
c) >80 % Detail Fracture
d) ~70 % Detail Fracture
e) >80 % Detail Fracture
f) ~40 % Detail Fracture

Type of ties and fasteners ....a) hard timber sleepers and hey-back
b) hard timber sleepers and hey-back
c) hard timber sleepers and hey-back
d) hard timber sleepers and hey-back
e) hard timber sleepers and hey-back
f) hard timber sleepers and hey-back

Geographical location......................a) North of Torneträsk (km ~1465)
b) Krokvik–Rautas (km 1431+200)
c) Rensjön–Bergfors (km ~1450+500)
d) Stenbacken–Kaisepakte (km 1475+682)
e) Stenbacken-Kaisepakte (km 1476+630)
f) not known

Time of year.......................................a) –
b) winter
c) winter
d) winter
e) winter
f) winter

* The cracks are indicated as subsurface initiated in the report. Note that it may however be that the cracks initiated at the surface and the “initiation” depth really indicates depth at downward deviation. This is very hard to verify/falsify from the report.

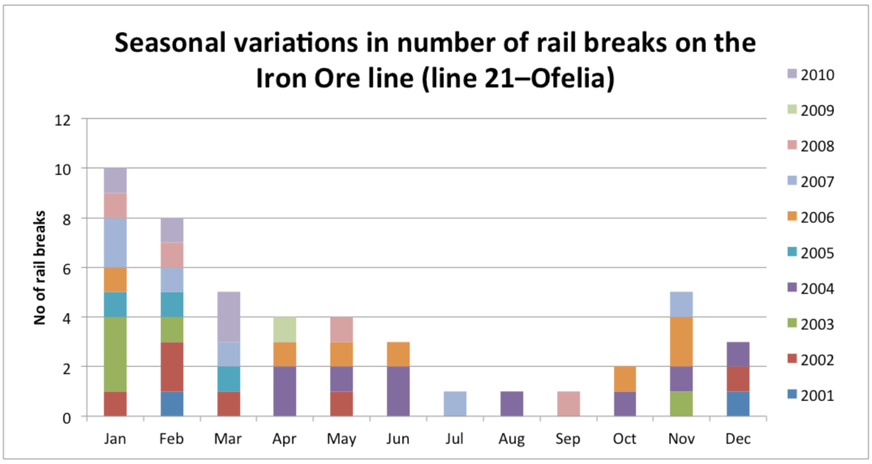
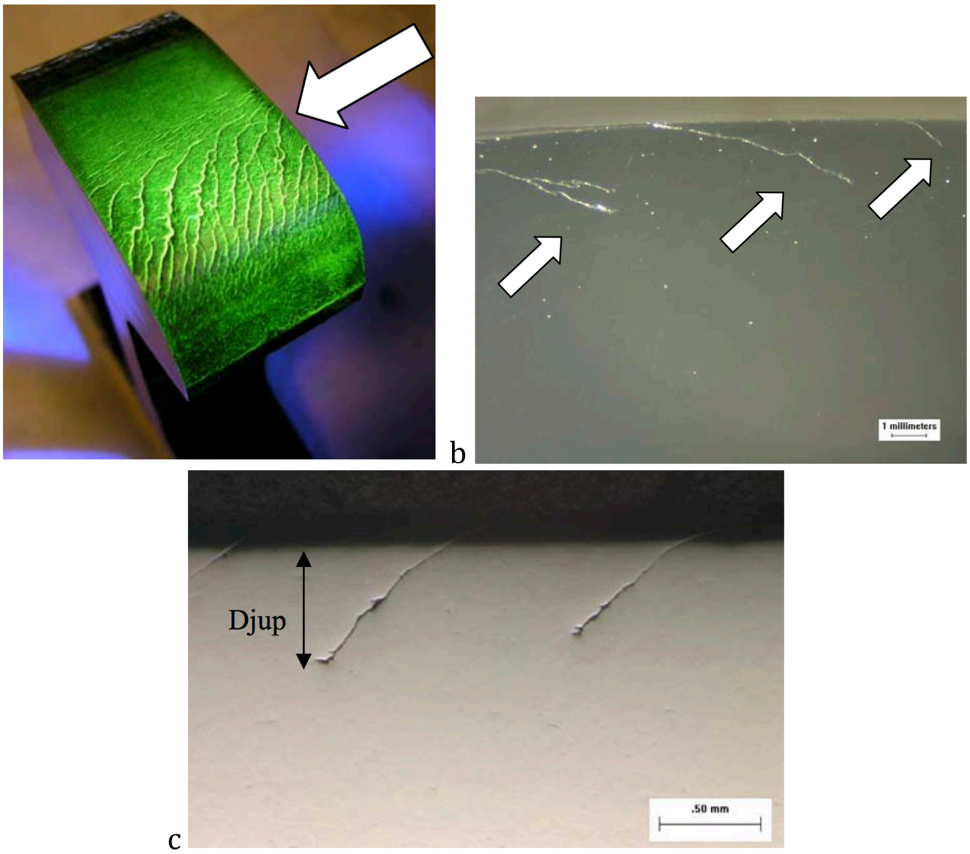
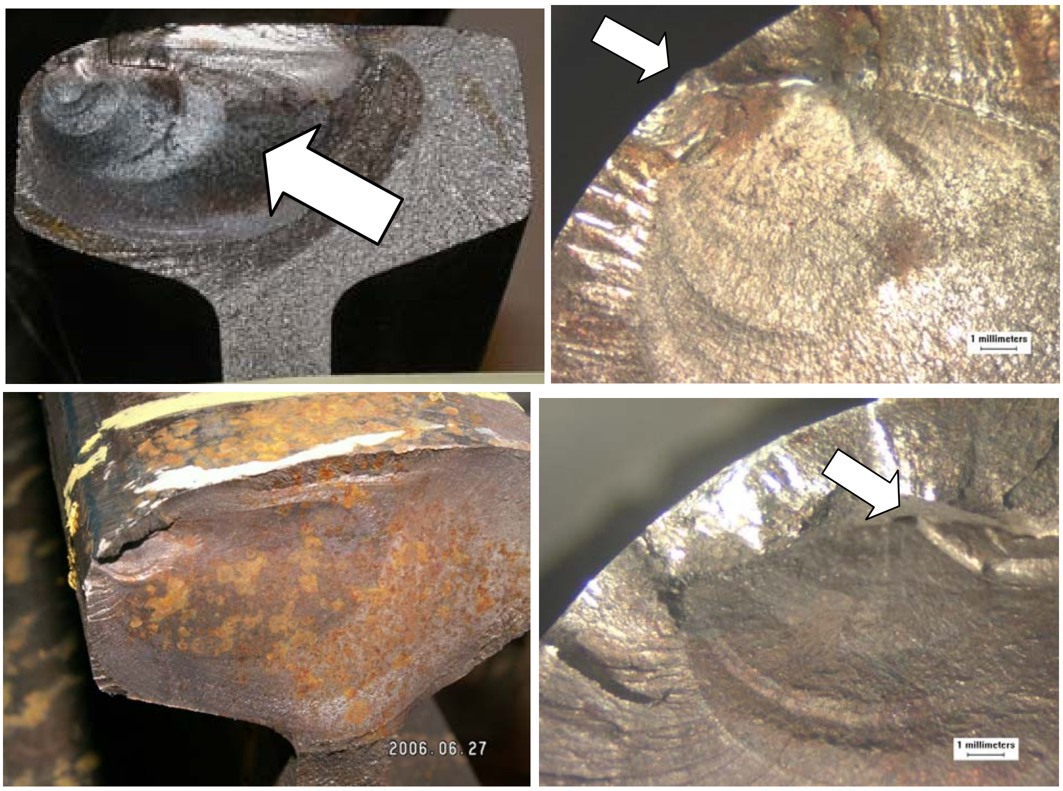


Figure 5 Annual variations in the number of rail breaks on part of the Swedish Iron Ore line. Picture courtesy Kalle Karttunen.



a b c

Figure 6 Investigations of the headchecks from the rail sample taken out north of Torneträsk. **a**) Headchecks at the top of the rail **b**) Transversal section **c**) longitudinal section



b c

Figure 7 Fractures surfaces of the investigated rail sections **b**–**f** as detailed above.

Comments

With the exception of rail **f**, the crack size at fracture is fairly constant between the rails. Note that the traffic on the line is almost uniform (heavy haul) and that all failures occurred during winter.
The influence of winter conditions in Sweden can be estimated from Figure 5. Note that the distribution over the year is very similar to that in Russia.

UK – case study

Data and picture courtesy Claire Davis, University of Birmingham (sample provided by Tata steel)

Laboratory evaluated cracks

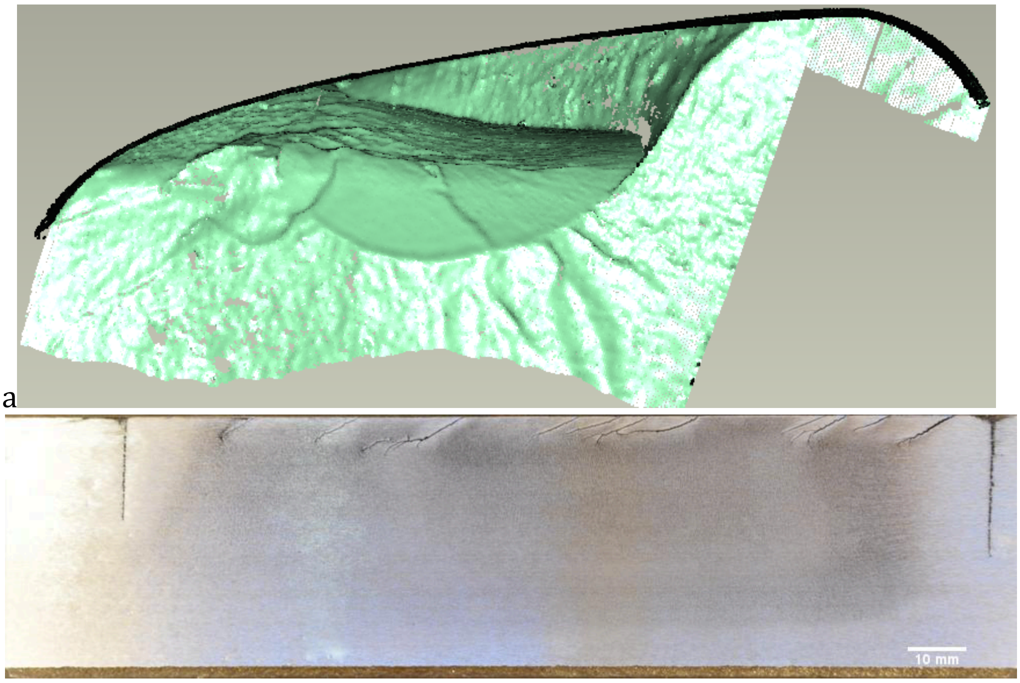
Rail grade 220

Service environment .... Passenger

Depth at downward deviation ...... **a**) 7.5 mm (broken open crack)
b) 5 mm (section with multiple cracks)

Geographical location .... UK

Fracture



a

b

Figure 8 **a**) Crack broken open and measured with laser scanning
b) Sectioning of a rail surface containing multiple cracks.

USA, Norfolk Southern Railway – case study

Data and picture courtesy Brad Kerchof, Norfolk Southern Railway

Data related to five fractures (four of which reported here). The fractures are reverse TDs – cracks originated in plastic flow at bottom of gage face.

Rail grade .... 2003 RMSM, Head Hardened
Rail section 141RE
Service environment .... Freight
Track curvature .... 12 degrees, high side
At a stress concentrator .... No
Type of ties and fasteners .... 8 x 18” tie plates with Pandrol e clips
Geographical location .... Kimball WV
Time of year (if service break) ..... December 26, 2013

Fractures

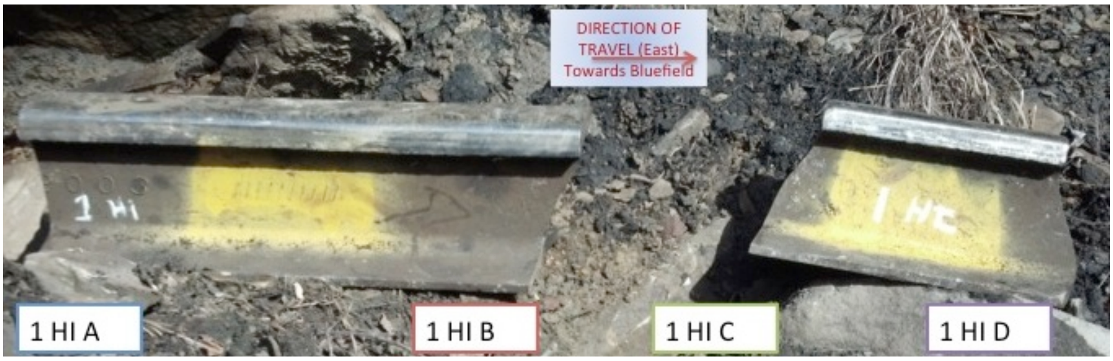


Figure 9 Overview of fractured rail

Figure 10 Fractures at sections 1HiA (a) and 1HiB (b)

a b

Figure 11 Fractures at sections 1HiC (a) and 1HiD (b)

Comments

The fractures have initiated as fatigue cracks related to plastic flow at the bottom of the gauge corner. At final fracture the fatigue crack size corresponded from roughly 17% for HiA, HiB and HiC to around 5% for HiD.

The fracture was in mid December, which means temperature effects would influence the rail. Note that this is a multiple fracture. Thus, the HiD fracture may have been affected by significantly increased load magnitudes owing to the other fractures.

USA, BNSF railways – case study

Data and picture courtesy David C. Sheperd, BNSF Railway

Rail .... **a**) 112lb or 115lb rail
b) RE116
c) 112 RE OH BSC LACK
d) RE115. 115 RE CC BETH LACKAWANNA 1975
e) 136-10 CC CF&I 1994
f) RE115LB. 11525 RE CC

Service environment......................... **a**) Freight, speed 40 mph,
b) Freight, speed 49 mph
c) Freight, speed 70 mph
d) Freight, speed 70 mph
e) Freight, speed 60 mph
f) Freight, speed 60 mph

Track curvature.................................. **a**) 0°
b) 2°
c) 0°
d) 0°
e) 1°
f) 0°

Crack size at fracture .... **a**) 25% Detail Fracture
b) 45% Detail Fracture
c) 10% Detail Fracture
d) (estimated 75%) Detail Fracture
e) 25% Detail Fracture
f) 50% Detail Fracture

Type of ties and fasteners.............. **a**) Timber tie 2008
b) Timber tie 2002
c) Timber tie 2011
d) Timber 2008
e) Timber ties 2007
f) Timber ties 2000

Geographical location .... **a**) West Quincy, MO BNSF Hannibal Sub LS14 MP137
b) Lester, IA BNSF Marshall Sub LS 197 MP152.3
c) Lohman, MT BNSF Milk River Sub LS 35 MP418.7
d) Hannibal, MO BNSF Hannibal Sub LS 14 MP136
e) Vaughn, NM BNSF Clovis Sub LS7100 MP788.5
f) Hastings, NE BNSF Hastings Sub LS 2 MP156.5

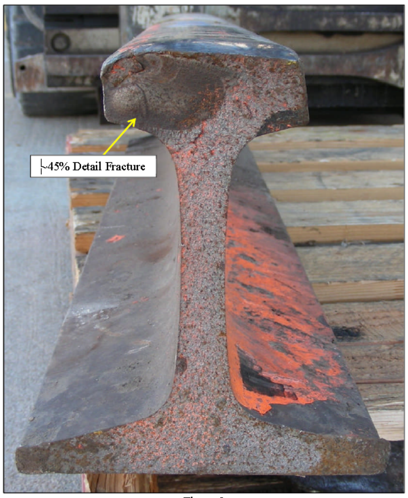
Time of year (if service break) .....**a**) February 10, 2012
b) November 04, 2013(?)
c) September 21, 2012
d) February 05, 2013
e) March 24, 2013
f) June 06, 2013

Comments

There is a rather large deviation in critical crack sizes for these rails even though the initiation site seem very similar.

Fractures


a



b


c

d


e


f

Figure 12 Overview of fractured rails

USA, BNSF railways – case study, part II

Data and picture courtesy David C. Sheperd, BNSF Railway

Rail ....**a**) 1946 Illinois 132# RE
b) 136# CC CF&I 1994
c) 115# RE Tennessee 1980
d) 132# RE CC CF&1 1953
e) 132# RE Illinois 1979
f) 136# RE CC CF&I 1973
g) 115# RE CC CF&I 1949

Service environment.........................**a**) Freight, 16.5 annual MGT
b) Freight, 186 annual MGT
c) Freight Siding, ~13 MGT Annually
d) Freight, 44 annual MGT
e) Freight
f) Freight 15.5 annual MGT
g) Freight and passenger siding estimate 13 MGT Annually

Track curvature..................................**a**) 2’ 0”
b) 2’ 0”
c) 0°
d) 0°
e) 0°
f) 4’ 0”
g) 0°

Crack size at fracture ....**a**) (estimated 10% Detailed fracture)
b) (estimated 25% Detailed fracture)
c) (estimated 40% Detailed fracture)
d) (estimated 40% Detailed fracture)
e) (estimated 15% Detailed fracture)
f) (estimated 15% Detailed fracture)
g) (estimated 15% Detailed fracture)

Type of ties and fasteners..............**a**) Wood ties, cut spikes
b) Wood ties, cut spikes
c) Wood ties, cut spikes
d) Wood ties, cut spikes
e) Wood ties, cut spikes
f) Wood ties, cut spikes
g) Wood ties, cut spikes

Geographical location ....**a**) El Paso Sub New Mexico, USA
b) Clovis Sub, New Mexico USA
c) Barstow Sub, Illinois USA
d) Boise City Sub, Texas USA
e) Canyon Sub, Wyoming USA
f) El Paso Sub, New Mexico USA
g) Ft Worth sub, Texas USA

Time of year (if service break) .....**a**) October 2013
b) March 2013
c) October 2013
d) November 2012
e) September 2012
f) November 2012
g) December 2012

Fractures

a

b

c

d

e 

f 

g 

Figure 13 Overview of fractured rails

Comments

Note that the critical crack size is very roughly approximated from the photos. Although there is considerable scatter, there is consistency in critical crack sizes and initiation sites.

Concluding remarks

There is a wide variation in critical crack sizes corresponding to transversal rail breaks. Possible reasons for this fact include:

- Variations in stress free temperatures
- Influence of cold climate (cf the influence of winter conditions in Russia and Sweden)
- Increased loading from other rail defects (or due to adjacent fracture)
- Support conditions
- Load magnitudes causing the final fracture
- Rail quality
- ...

Note that e.g. the investigated rails from the Swedish Iron Ore line have a fairly consistent critical crack size. This implies that it should be possible to obtain a state where the critical crack size is fairly constant. This might require fairly uniform traffic and track conditions, which is the case on the Swedish Iron Ore line.

Wear state seems to have limited influence on the critical crack size (as percentage of head area).

There is an indication that (on average) the critical crack size may be somewhat smaller in curves.

Depth of transversal deviation tends to be around 5 mm. However this depth is generally difficult to identify and subjected to a major scatter.

The information in this report provides a perspective to the results that have been obtained in work carried out on rail breaks e.g. in the European projects INNOTRACK (http://www.innotrack.eu/) and D-RAIL (http://d-rail-project.eu/). In these projects (long) crack growth has been predicted and influences of various parameters established. Further alarm limits for wheel impact loads have been established in the UIC-led HRMS project. These limits were established based on a prediction of which combinations of rail crack size, wheel impact load, vehicle and track conditions that will result in a rail fracture.

In addition to broaden the knowledge gained from these projects, it is also believed that the current report can help networks assess whether they have a good control on stress free temperatures (resulting in a fairly stable critical crack size) and to improve ultrasonic testing (knowing the depth for transversal propagation provides a basis for establishing the latest stage when cracks should be detected).

Naturally a lot of unknowns remain before the risk of rail breaks is fully managed. One important aspect in this strive is to recognize that passengers travelling by rail are typically 50–100 times safer than those travelling by car. Thus imposing very costly measures with limited effects that drives travel to road is a sub-optimization. The same holds for freight where the benefits of preventing rail breaks and thereby delays and in rare cases (see ERA reporting on freight derailments) human losses should be contrasted to the risk of transferring operations to less safe and environmentally friendly means of transportation.

Annex I – summary of core data

Compiled by Eric Magel, NRC–CNRC

			rail (H/L)	initiation depth	defect size	rail grade	years in service	rail section	track curvature	axle loads	annual tonnage	speed		date of break
Robert Frohling	Transnet	South Africa		6 mm		Thyssen HH	7	UIC60	604	26				
				7 mm		CrMn	27		804	26				
Claire Davis	Birmingham	UK		7.5 mm		220							passenger service	
Sergey Zakharov		Russia	L ?										some statistics, showing broken rails 8x more frequent in winter	
Brad Kerchof	NS	USA	H		5-17%	RMSM 2003		141RE	240 (12o)				"reverse TD's"	
Dave Sheperd	BNSF	USA	H		25%			112lb or 115lb rail	0			40 mph	timber ties	Feb-12
			H		45%			RE116	2			49 mph	timber ties	Nov-13
			H		10%	OH BSC LACK		112RE	0			70 mph	timber ties	Sep-12
			H		75%	CC BETH LACK 1975		115RE	0			70 mph	timber ties	Feb-13
			H		25%	CC CF&I 1994		136-10	1			60 mph	timber ties	Mar-13
			H		50%	115RE CC		RE115	0			60 mph	timber ties	Jun-13
Dave Sheperd	BNSF	USA	H		10%	Illinois 1946		132RE	2		16,5		wood ties, cut spikes	Oct-13
			H		25%	CC CF&I 1953		136RE	2		186		wood ties, cut spikes	Mar-13
			H		40%	Tennesee 1989		115RE	0		13		wood ties, cut spikes	Oct-13
			H		40%	CC CF&I 1953		132RE	0		44		wood ties, cut spikes	Nov-12
			H		15%	Illinois 1979		132RE	0				wood ties, cut spikes	Sep-12
			H		15%	CC CF&I 1973		136RE	4		15,5		wood ties, cut spikes	Nov-12

			H		15%	CC CF&I 1949		115RE	0		13		wood ties, cut spikes	Dec-12
Xin Zhao	SWJTU	China		6-8 mm					this was a general review of the case in China					
Zhou Qingyue	CARS	China	H	8-15 mm		980		60 kg	600	21-23t	64-67		heavy curvature mountain territory	
									1000		70			
									800		79			
Tamara Gronowicz / Anders Ekberg	Trafikverket / Chalmers	Sweden	H?	2 mm	50%	1100	16	BV50	?	30t	7 MNT	60/70 mph	hardwood, hey-back	winter 2006
			H?	3 mm	80%	?	?	BV50	?	30t	7 MNT	60/70 mph	hardwood, hey-back	winter 2006
			H?	3 mm	70%	?	?	BV50	?	30t	7 MNT	60/70 mph	hardwood, hey-back	winter 2006
			H?	6 mm	80%	1100	16	BV50	?	30t	7 MNT	60/70 mph	hardwood, hey-back	winter 2006
			H?	5 mm	40%	?	?	BV50	?	30t	7 MNT	60/70 mph	hardwood, hey-back	winter 2006