Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 213 (2018) 255–261

Procedia Engineering

www.elsevier.com/locate/procedia

7th International Conference on Fatigue Design, Fatigue Design 2017, 29-30 November 2017, Senlis, France

A study on lifetime of a railway axle subjected to grinding

Xavier LORANG[(a)], Yann CHEYNET[(b)], Philippe FERAUD[(b)], Yves NADOT[(c)]

[a]*SNCF, Innovation & Recherche, 40 Avenue des Terroirs de France - 75611 Paris Cedex 12*
[b]*SNCF, Agence d'Essai Ferroviaire, 21 Avenue du Présiden Allende 94407 VITRY SUR SEINE Cedex*
[c]*Institut Pprime, ISAE-ENSMA,11 Boulevard Marie et Pierre Curie,BP 30179 F86962 FUTUROSCOPE CHASSENEUIL Cedex*

Abstract

For security requirements, no fatigue failure of axles is admitted in railway industry. Design process of axles must ensure that there is no crack initiation during its life. Maintenance inspections guarantee that no defect initiates critical propagation of fatigue cracks. In order to remove surface defects, wheel grinding is realized during maintenance task. The present paper addresses a lifetime comparative study of an axle with and without grinding operation. The goal is to investigate the influence of the grinding parameters on the lifetime of axle. In the first part of the paper, the context of maintenance of railway axle is briefly described and the grinding process is presented. The grinding process modifies the roughness, the microstructure of the surface and induces residual stresses: some experimental results are presented. In the second part, the case of a ground axle is considered without defect. A study of the effect of the grinding process on the lifetime of fatigue samples is presented. In the third part, the case of a ground axle is considered with defects. In this case, a study of the effect of the grinding process on the lifetime is presented for different types of defects. Fatigue tests results on specimens are presented. Numerical simulations results for lifetime evaluation are also presented.

Peer-review under responsibility of the scientific committee of the 7th International Conference on Fatigue Design.

Keywords: grinding, damage tolerance, railway axle

Peer-review under responsibility of the scientific committee of the 7th International Conference on Fatigue Design.
10.1016/j.proeng.2018.02.026

1. Maintenance of railway axle and grinding process

1.1. Maintenance of axles

The railway axles are subjected to high mechanical loads. The risk of the occurrence of fatigue cracks is perfectly controlled by the design. In spite of this, cracks could be initiated in different zones of the axles on defects like shocks, corrosion pitting or machining striation. On the axle journal, the origin of cracks could be an anomaly in the bearings. On the seats of wheels, gear wheels or brake discs, the problem comes from the fretting. In the body, every defect could cause the initiation of cracks: corrosion, shocks or machining striation.
To avoid such a failure, two philosophies are opposed.
The first is based on the high frequent and regular check of axles by NDT to try to detect cracks before the fracture. The second is to check the entire surface at regular inspection of the axles to detect all defects that can lead to cracks. If defects are found in maintenance visits, these defects have to be erased by machining or grinding.
SNCF chooses this second solution for the maintenance of the wheelsets. First axles are shot-blasted to strip painting, to perform magnetic particle testing. If some indications are found, surface around defect is grinded. The maintenance specifications impose criteria for this operation, geometry of the grinded area and direction of grinding. The documents also force to use specific equipment.
However some cracks were found in the middle of grinded zone. Crack initiation could be located in one point (figure 1.a) or on many points..

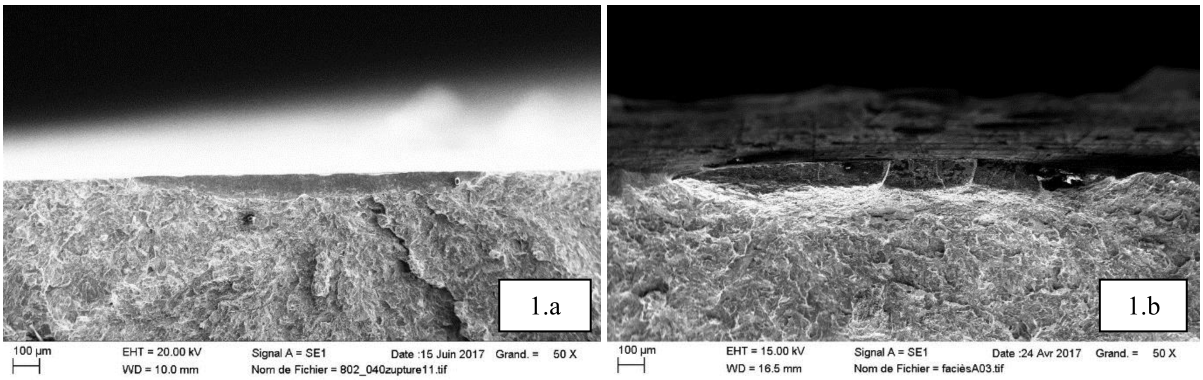


Figure 1 : Fracture surface - fatigue crack detected in the body of railway axle (SEM observation)

To explain these different cases, the residual stresses induced by grinding operation could be investigated.

1.2. The effects of grinding

A study started to try to determine the influencing of grinding on two steels used for axles manufacturing, C40 (EA1N) and 25CrMo (EA4T). Specimens were machined in different axles to study influence of grinding on microstructure, roughness and residual stresses. Different parameters like rotating speed, speed rate, strength and orientation were used to grind the specimens on an automatic grinding-bench.

The influence of grinding is obvious, with the cold hardening and grain deformation on the surface. The thickness of this modified layer reaches 20 µm for the ferrito-perlitic steel and 10 µm for the bainitic steel (figures 2.a, 2.b).

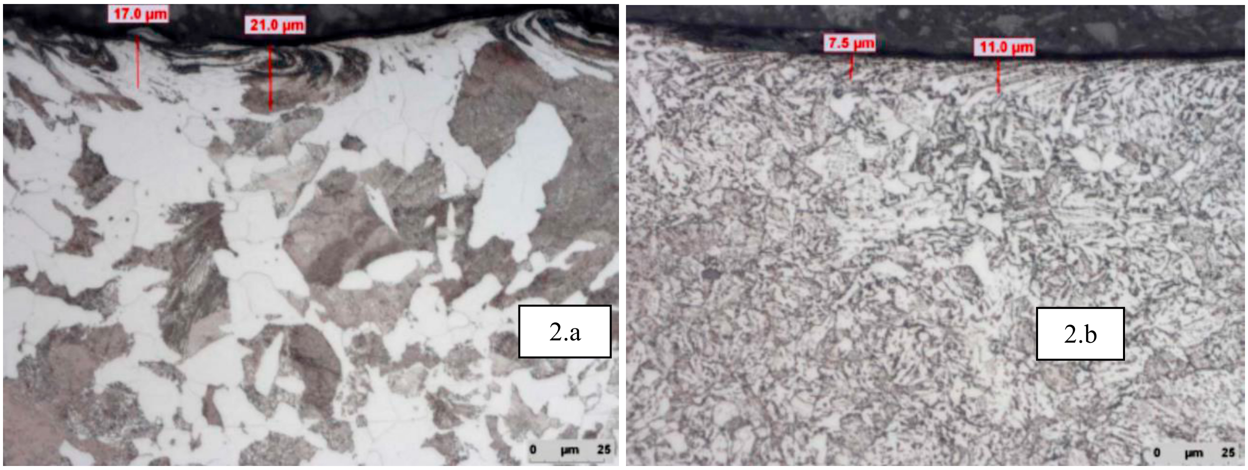


Figure 2 : Microstructure

The roughness in the grinding area is measured: Ra = 4 µm and Rt = 40 µm.
Finally the residual stresses are analyzed by X-ray diffraction. The results show (Figure 3) that grinding introduces tensile residual stresses on the surface of the specimens. The values depend on the orientation of grinding, residual stresses increase for the direction of grinding striation. These results have been obtained on specimens before the application of fatigue cyclic loading.

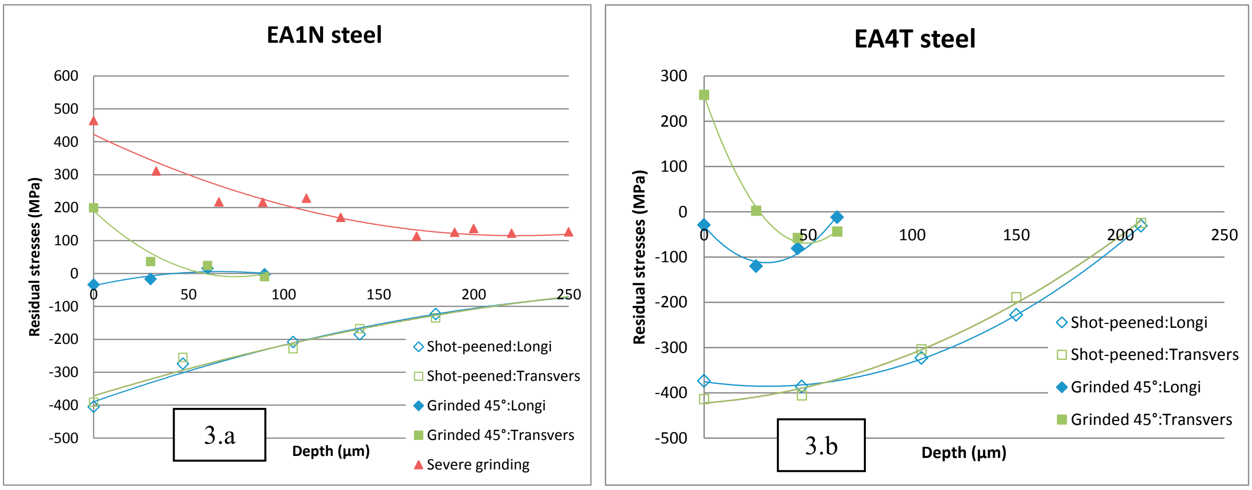


Figure 3 : Residual stresses in depth (a) EA1N Steel (b) EA4T Steel

2. Experimental investigations of the effect of grinding on fatigue specimens

What is the most influencing parameter on the lifetime of the axles: Is that the roughness and the grinding striation orientation or the residual stresses?
To answer, fatigue tests are performed on different specimens with three types of grinded surface longitudinal, transversal and 45° orientation with crossed passes (figure 4). The results are compared with the normal states, shot-blasted and machined surface.

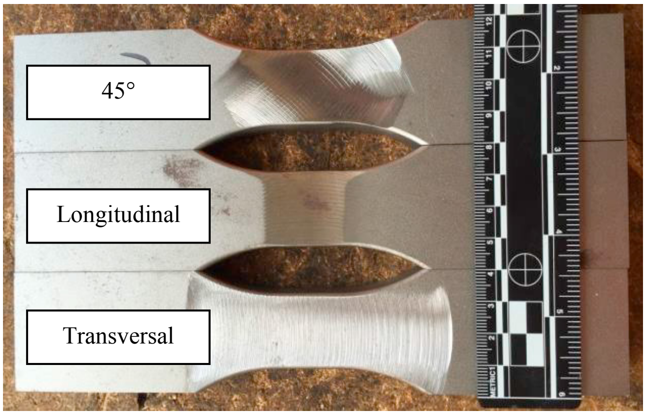


Figure 4 : Four points fatigue bending specimens - machining + shot blasting + grinding

Specimens are loaded in 4 points bending with load ratio 0.1, to insure that initiation will always occur on the grinded side of the specimen.
First results confirm the lowering of 14%, in the fatigue limit*. The fatigue limit reaches 215 MPa for the shot–blasted surface, 209 MPa for the machined surface and 185 MPa for shot-blasted and 45° grinded surface.
The other tests are still in progress. First specimens for the transversal grinding failed under loading lower than 170 MPa.

3. On the effect of grinding on an axle with a crack defect

3.1. Context and hypothesis

The goal of this section is to present simulation results of the propagation of a radial crack starting on the surface of a railway axle C40 steel (EA1N) subjected to grinding. The axle is subjected to variable amplitude loading. The figure 5 shows a sequence of bending moment at a given cross section of the axle. This bending moment is supposed to be constant over one revolution of the axle (1 cycle). This sequence is repeated during simulation.

A surface semi elliptical crack (a/c=1.01) is considered. The stress field (figure 4b) $\sigma(d,t)=\sigma_{res}(d)+\sigma_{bend}(d,t)$ is composed of the bending stress and residual stresses due to grinding. We assume the stress field is only in the axial direction (the dominant stress which open the crack).

* Endurance limit: amplitude loading ($1/2(\sigma_{max} - \sigma_{min})$) after 10 000 000 cycles and 50 % in fracture probability.

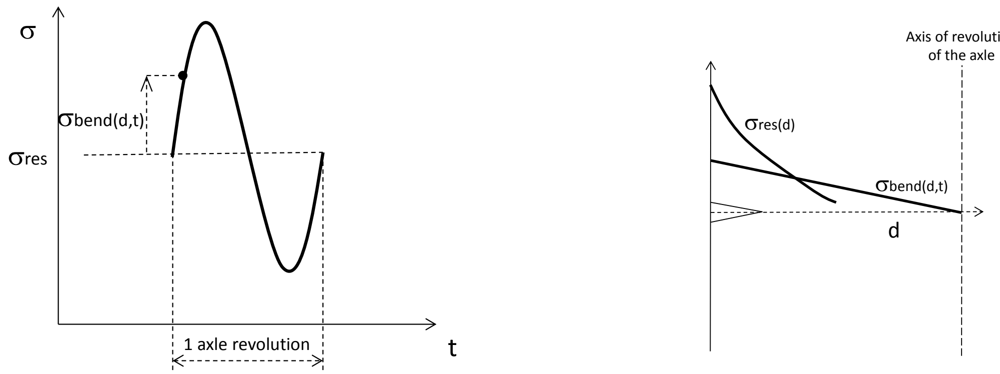


Figure 4b : Stress field near the semi-elliptical crack

A normalized residual stress profile in depth is represented figure 6. X is the stress at the surface. A residual stress profile measured on a scale 1 axle subjected to grinding has been used to build the shape of the curve.

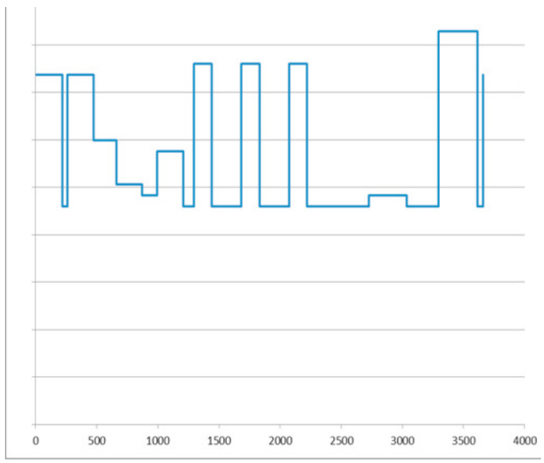


Figure 5 : Simplified bending moment history as function of the number of cycles

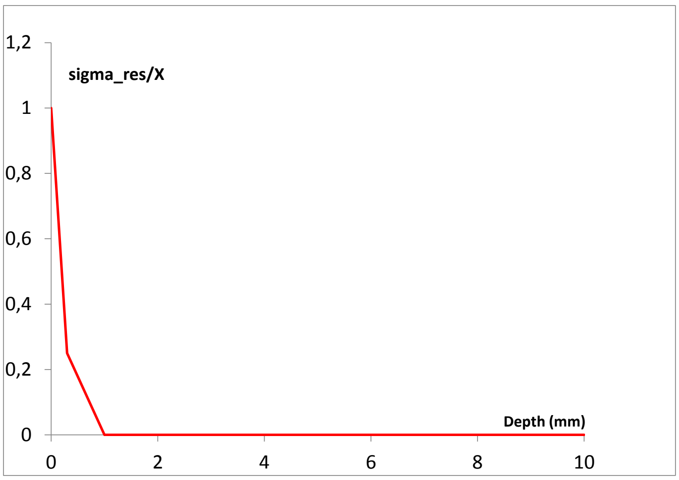


Figure 6 : Normalized residual stress profile by the stress at the surface X

We consider the NASGRO crack propagation law defined as follow:

$$\frac{da}{dN} = C.\left(\frac{1-f(R)}{1-R}.\Delta K\right)^n . \frac{\left(1-\frac{\Delta K_{th}(a,a_0,R)}{\Delta K}\right)^p}{\left(1-\frac{Kmax}{Kc}\right)^q}$$

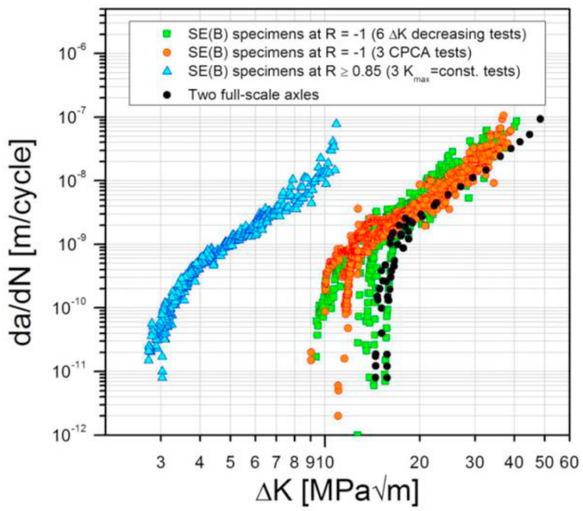
Where, f is the opening function, R is the load ratio, Kc is the fracture toughness, Kmax is the maximum of SIF, $\Delta K_{th}$is the SIF threshold amplitude, a is the crack length and a0 is the El Haddad parameter [2].

The SIF threshold amplitude for short crack can be defined from the SIF threshold amplitude for long crack with the following formula :

$$\Delta K_{th(S)}(a,a_0,R) = \Delta K_{th(L)}(R)\left(\frac{a}{a+a_0}\right)^{0.5}$$

Experimental tests has been conducted by Beretta et al [1,3] on SE(B) specimens and real axles (figure 7). These results show variability of the threshold for specimens and also for full scale axles. Figure (7b) shows thresholds for two approaches: Compression Pre-cracking Constant Amplitude (CPCA) and Compression Pre-cracking Load Reduction (CPLR) followed by ΔK decreasing techniques. From these results, following parameters are identified (for R=-1):

$$\Delta K_{th(L)} = 13.8\, MPa.m^{0.5}\ and\ \ a0 = 0.8\, mm.$$



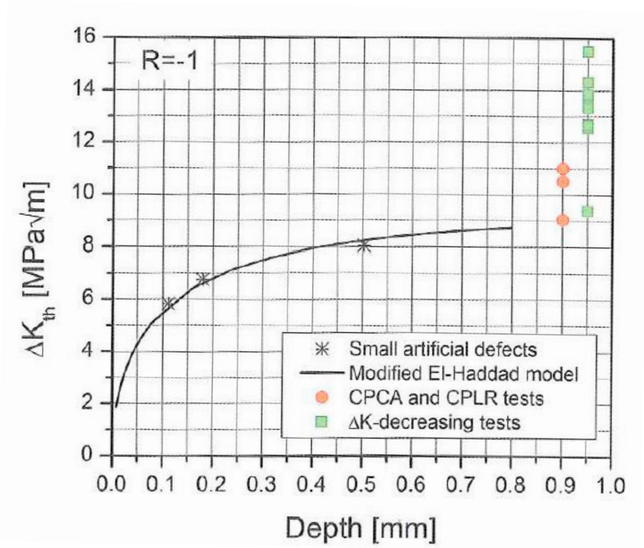


Figure 7 : (a) Constant amplitude loading growth curves obtained from SE(B) specimens and full scale axles (b) SIF Thresholds amplitude function of size of crack (from [1,3]) obtained by different methods

3.2. *Critical crack size and residual stresses*

Crack propagation computations have been realized with the NASGRO software [2]. Different initial crack sizes have been considered with different values of residual stresses at the surface X. Behind a certain value of X, it is necessary to consider a minimum value of initial crack to obtain the effective propagation of the crack. The results are presented figure 8. It is important to note that for a X value of 165 MPa, the critical size of the crack becomes zero. This result allows characterizing the severity of grinding in terms of residual stresses.

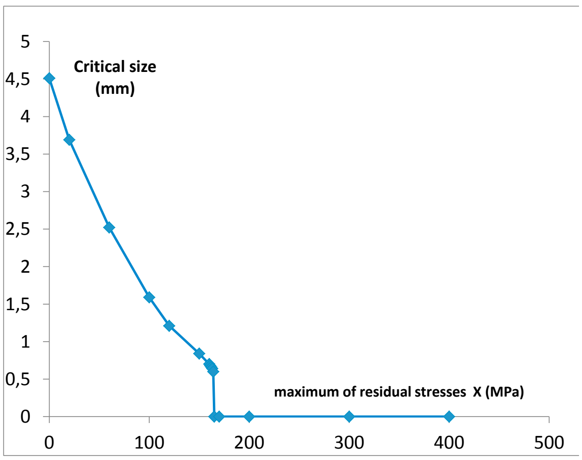


Figure 8 : Critical crack depth as function of the surface residual stress

3.3. Crack Propagation analysis

A crack propagation computation has been realized for X=460 MPa (which correspond to the severe grinding measured figure 3), and for the variable amplitude loading defined in figure 5. The initial size of the crack is 10 µm. The results are presented in figure 9. We can observe that the propagation is very slow at the beginning: for the last 15 % of the number of cycles, the crack depth switches for 0.2 mm to 5 mm.

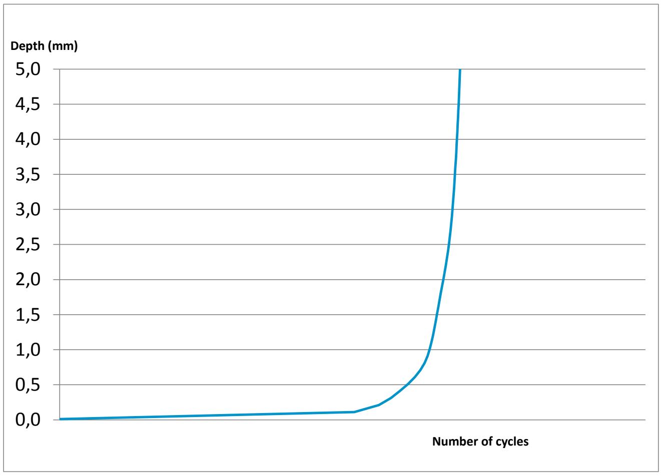


Figure 9 : Crack depth as a function of number of cycle for variable amplitude loading

4. Conclusions

The context of maintenance of railway axle and the effect of the grinding process has been described. A study of the effect of the grinding process on the lifetime of fatigue samples has been presented.
In the third part, the case of a ground axle is considered with crack in the ground zone. Crack propagation simulations results have been presented: a critical surface residual stress has been evaluated and the lifetime of the axle has been computed for variable amplitude loading.

References

[1] S. Beretta and M. Carboni, «Variable amplitude fatigue crack growth in a mild steel for railway axles: Experiments and predective models,» Department of Mechanical Engineering, Politecnico di Milano, I-20156 Milano, Italy, 2009.

[2] NASGRO, «Fracture Mechanics and Fatigue Crack Growth Analysis Software,» November 2012.

[3] S. Cantini, S. Beretta, “Structural reliability assessment of railway axles”, book, Lucchini RS, 2011