THE INFLUENCE OF OVERLOAD ON THE LIFETIME OF A RAILWAY WHEELSET

Redouane ZELLAGUI[1], Ahmed BELLAOUAR[2]

The railway wheelset are the essential parts in the bogie of a train, and its' failure creates a big problem in the railway transport; during service of these parts we noticed a premature deterioration. The aim of our paper is to determine the lifetime of the wheelset under permanent load and overload, also we want to present the influence of the frequency on the crack propagation for the high strength steel. The modeling of wheelset was performed using SOLID WORKS software and imported into the finite element code ANSYS.

Keywords: Axle, Lifetime, Crack, Failure, Stress.

1. Introduction

The bogie is an important mechanism composed of different elements that contribute the transmission of engine torque as well as to the transmission of the forces exerted by the gear to the wheels. From a work perspective, the bogie comprises of several parts, the main one is the chassis, the other two sets are (axles and wheels) and the last sets are (spring, boxes, wheelset and brake discs). The railway wheelset is an essential element in the bogie and it is subjected to different loads under whose action it may fail. Any problem in these parts creates a big problem on human life. The railway wheelset is designed for working a long time (30 years) and for this goal extensive research is performed. Our approach is to determine the stress field according to a dynamic loading in order to predict the critical areas or regions. The numerical modeling became an important tool to gain more time and to facilitate the shaping of complex systems and predicting models so as to achieve optimal designs.

A literature review paper by focusing on the technique of modeling of fatigue crack growth in the material of railway wheelset under regular and random loading was developed by O. Yasniy (2012) which determined the influence of the stress ratio on the crack propagation and statistical distributions of crack [1]. M. Luke determined experimentally the crack growth in railway wheelset for the commonly used steel and the high strength steel and he found the fatigue behavior of railway wheelset under variable load [2]. José Martínez-Casas presented an application of

[1] Department of Transport, University of Mentouri Brothers Constantine **1**, Algeria, e-mail: zellaguiredouane25@gmail.com.

[2] Department of Transport, University of Mentouri Brothers Constantine 1 Algeria, e-mail: bellaouar_ahmed@yahoo.fr.

the critical side in different elements of railway bogie (axles, wheels, rail) and the fracture behavior of the previous elements under harmonic load [3]. K. Hirakawa performed an analysis of different causes of failure for a railway wheelset and the fretting fatigue crack in the critical side of the wheelset. He also found how to improve the wheelset railway manufacture. Figure 2 shows the variable load applied on the wheelset, [4].

For explaining more of the importance of our study, Figure 1 (left) describes a big damage which happened in Italy in June 29th, 2009 when a train accident occurred due to the existence of a small crack in the wheelset (the crack wheelset is shown in the right picture). As a result of this accident, 32 people died and big damages occurred in the wagons.

Fig 1: Fracture in wheelset [8].

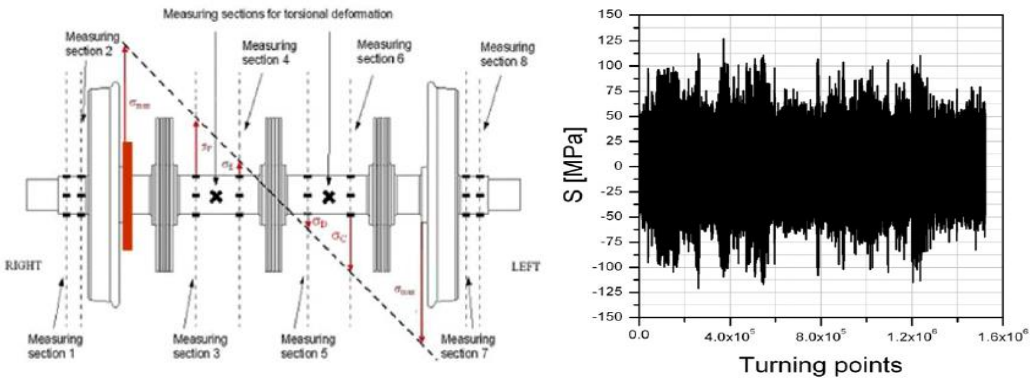

Fig 2: Typical stress-time history [4].

2. Fracture mode

The fatigue mechanisms show that, it is not often necessary to consider only the possibility of an existing crack, but also the crack growth propagation, to ensure that the cracks do not reach the critical length. It is necessary to have quantitative data to charactere the fatigue crack growth.

In 1960, Paris et al. have shown the relationship between fatigue crack growth (da / dN) and the stress intensity factor (K). Because the value of stress intensity factor changes during variable load, one defines the magnitude of the stress intensity factor: $\Delta K = K_{max} - K_{min}$, where K_{max} and K_{min} are the extreme values of K during the cycle. In logarithmic scale, the crack growth rate (da / dN) is shown in the Figure.3. three different zones can be noticed:

- ✓ Range I is characterized by the crack propagation threshold. The velocity goes to zero, for a value ΔK_{th} which is called propagation threshold.
- ✓ Range II, is the Paris law zone. It is characterized by the crack propagation velocity when ΔK increases. Paris et al. have linked the propagation velocity and magnitude of the ΔK by the relationship:

$$\frac{da}{dN} = C(\Delta K)^n \tag{1}$$

where C and n are experimental parameters depending on material and test conditions (load ratio, environment ...).

- ✓ Range III corresponds to a very rapid acceleration of the speed of crack. The stress intensity factor is close to the critical value Kc corresponding to the final failure.

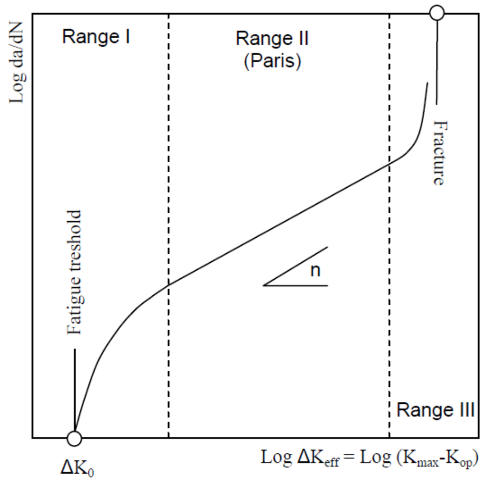

Fig 3. Fatigue crack extension characteristics (da/dN) based on ΔKeff.

3. The mechanical model

The studied mechanism is shown in Fig. 5. It is very important to present different parts of the bogie and the relation between this parts. Using this model we can determine different problems in the bogie and the dangerous area.

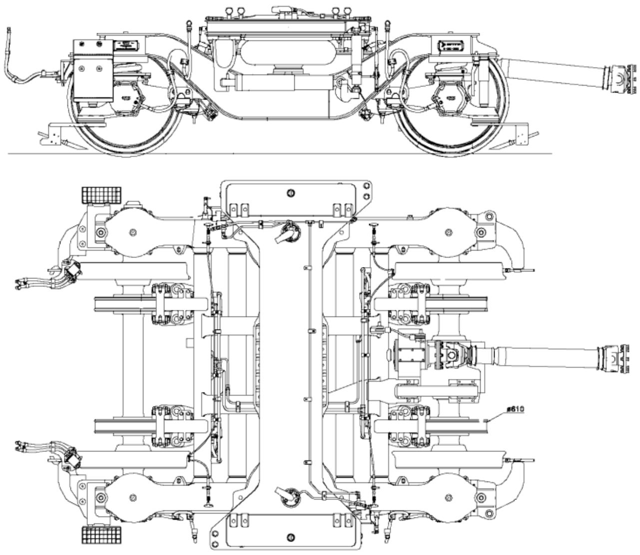

Fig 4: Scheme of railway bogie. [9]

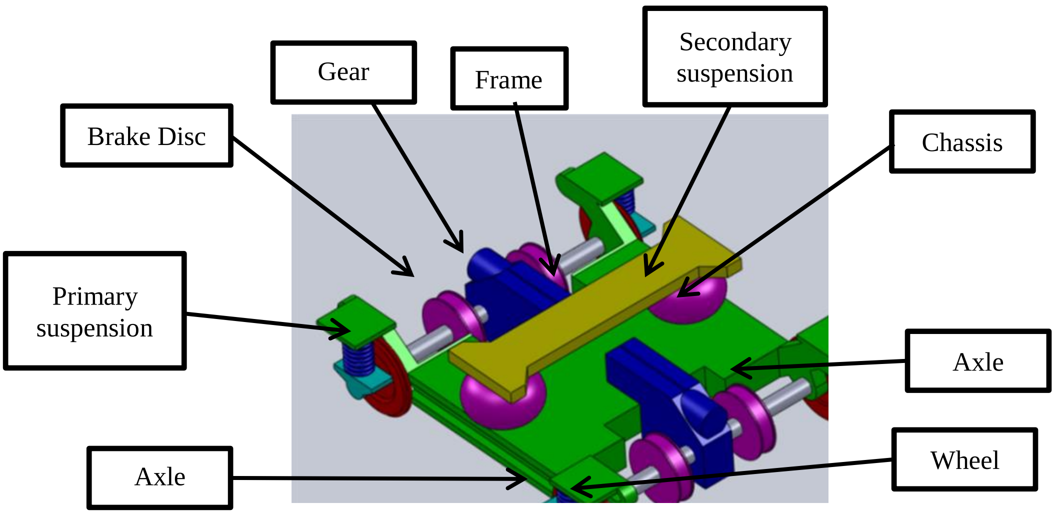

Fig 5: Numerical model of the railway bogie.

The calculations are done according to the information and conditions given by the clients, which are the train characteristics listed in Table 1.

Table 1

Train characteristic

	Value
Body mass	77600Kg
Chassis mass	500Kg
Wheel mass	500Kg
Spring factor of primary suspension	788MN/m
Damping factor of primary suspension	3.5KN-s/m
Spring factor of secondary suspension	6.11MN/m
Damping factor of secondary suspension	158KN-s/m
Maximum load in wheelset.	25 tonnes
Axle mass	370Kg

A detailed view of the studied wheelset is shown in Fig. 6. As seen in this figure, the solid shaft has been made as one body and its cross-section is circular. In several locations on the shaft, fillets with different radius are seen which act as stress concentrators.

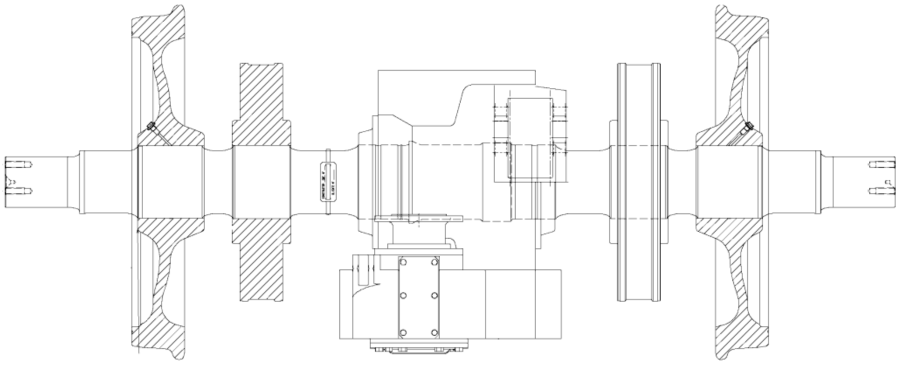

Fig.6. Detail of Railway wheelset [9]

In order to analyze the mechanical behavior of the railway wheelset, a general model using the Ansys software was realized. The applied mechanical properties are listed in Table 2. According to the previously defined loads, the critical areas of the wheelset are defined.

Table 2

Mechanical properties

Yield stress (MPa)	KI_C (MPa*m$^{0.5}$) Plane strain	KI_D (MPa*m$^{0.5}$) Plane stress	C	N
350	121	242	3e-12	3.43

The FE model of railway wheelset is shown in Fig. 7. The analysis model of the axle consists of 110453 nodes and 90265 elements. In this model, the x-axis is longitudinal, the y-axis is transversal and the z-axis is on the vertical direction respectively. Several loading cases were considered as to make a comprehensive study on the mechanical behavior of the wheelset using Ansys.

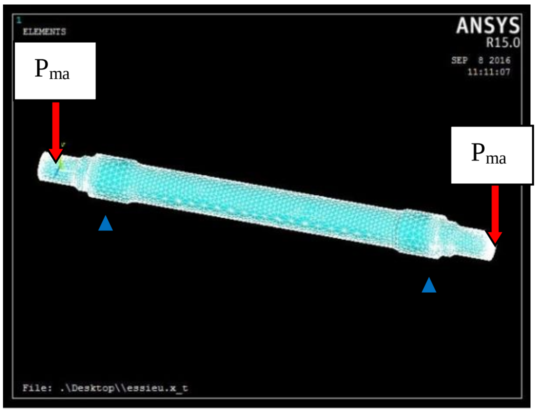

Fig 7: FE model of railway wheelset.

Generally, the form of the cracks in wheelset is semi elliptical, so for our geometric model a semi elliptical surface crack depth is chosen with depth *a* and width 2*c* (Figure 8).

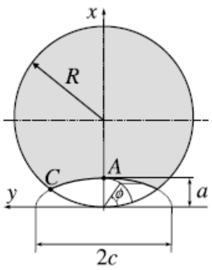

Fig.8: The elliptical crack, [7].

The calculation of stress intensity factor is given by relation (2), where $F_s\left(\frac{a}{c},\frac{a}{D},\frac{c}{D},\varphi\right)$ is a function of geometry.

$$K=\sigma F_s\left(\frac{a}{c},\frac{a}{D},\frac{c}{D},\varphi\right)\sqrt{\frac{\pi a}{Q}} \tag{2}$$

$$F_s=\left[M_1+M_2\left(\frac{a}{D}\right)^2+M_3\left(\frac{a}{D}\right)^4\right]gf_\varphi f_w \tag{3}$$

For: $\frac{a}{c} \leq 1$

$$M_1 = 1.13 - 0.09\left(\frac{a}{c}\right) \tag{4}$$

$$M_2 = -0.54 + \frac{0.89}{0.2 + \frac{a}{c}} \tag{5}$$

$$M_3 = 0.5 - \frac{1}{0.65 + \frac{a}{c}} + 14\left(1 - \frac{a}{c}\right)^{24} \tag{6}$$

$$g = 1 + \left[0.1 + 0.35\left(\frac{a}{D}\right)^2\right](1 - \sin\varphi)^2 \tag{7}$$

$$f_\varphi = \left[\left(\frac{a}{c}\right)^2 (\cos\varphi)^2 + (\sin\varphi)^2\right]^{1/4} \tag{8}$$

$$f_w = \left[\sec\left(\frac{\pi c}{2D}\sqrt{\frac{a}{D}}\right)\right]^{1/2} \tag{9}$$

4. Results and discussion

In our model of crack, we start from an initial crack length a_0 of approximately 4 mm. Each specimen was cycled at a stress ratio R = -1 and the nominal stress range of P_{max} = 7.5 MPa (pressure applied on the wheelset). Fig. 2 shows the difficulties in applying this type of load to our model. For this point, the problem has been simplified in two types of loading, in the second step; we have chosen that after each 10 cycles of constant amplitude one overload of 1.2P_{max}. The overload on the fatigue crack growth behavior of our study is shown in Fig. 9; we applied one cycle of 1.2P_{max} after each 10 cycles of constant amplitude of P_{max}.

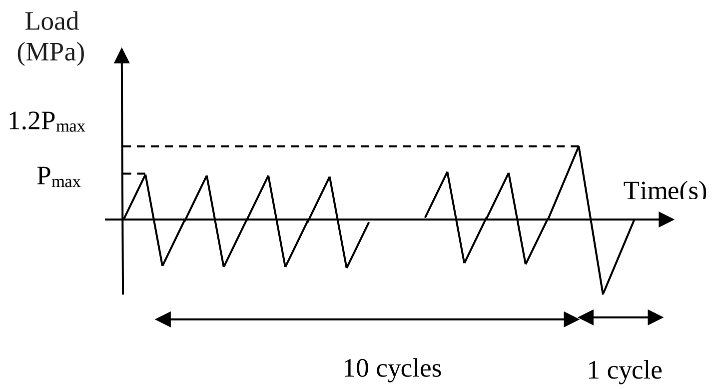

Fig.9: Overload spectra.

In Fig. 10 (a, b) we present the variation of the crack length with and without overload. So, we noticed that in figure 10 (a) the crack length is increasing slowly and from $8.9x10^9$ cycle it starts to increase quickly. In figure 10 (b) the crack length is increasing slowly up to $8.3x10^9$ cycles, when it begins to increase quickly.

Also, we noticed that in Figure 11(a) the crack growth is increasing slowly up to a crack length *a* = 70 mm, then it increases quickly. In Figure 11 (b) it can be seen that the crack velocity is small up to *a* = 50mm and then it begins to pertubate. In this point, we found that there is a big influence of overload on railway wheelset.

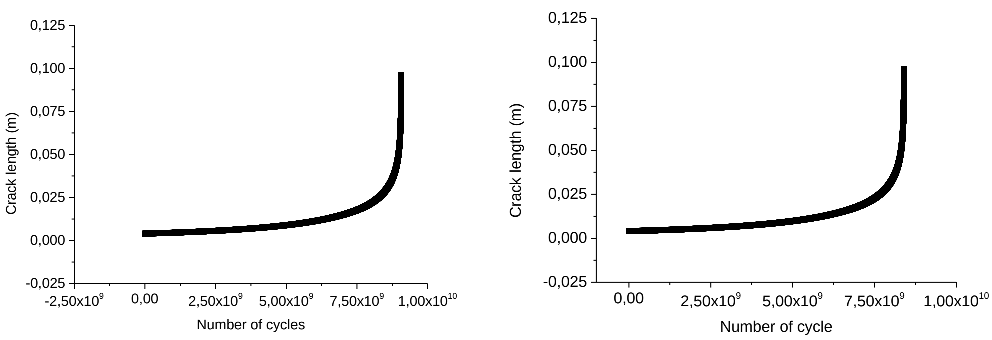

Fig.10 (a, b): Variation of crack length. (a) Without overload, (b) With overload

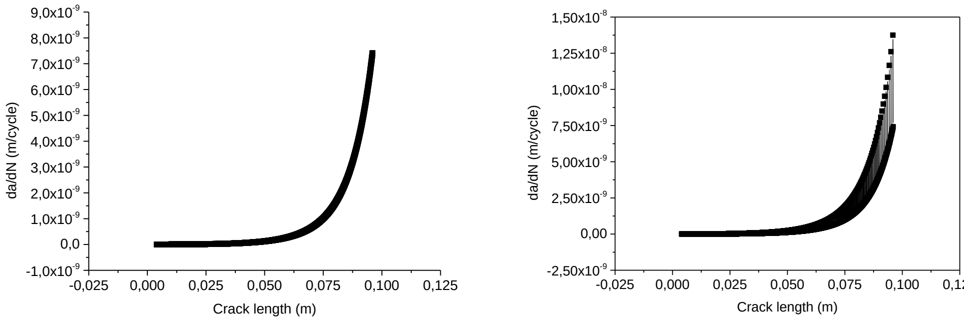

Fig.11 (a,b) :Variation crack growth. (a) Without overload, (b) With overload

Fig. 12 shows the influence of frequency on the life of the wheelset. We can notice that the relationship between the variation of the frequency and the lifetime is inversely proportional. The influence of frequency is very important. We found that when we decrease the frequency, an increase of the lifetime is noticed: $8.8887*10^9$ s in normal load, and $8.23198*10^9$ s in the case when we have an overload.

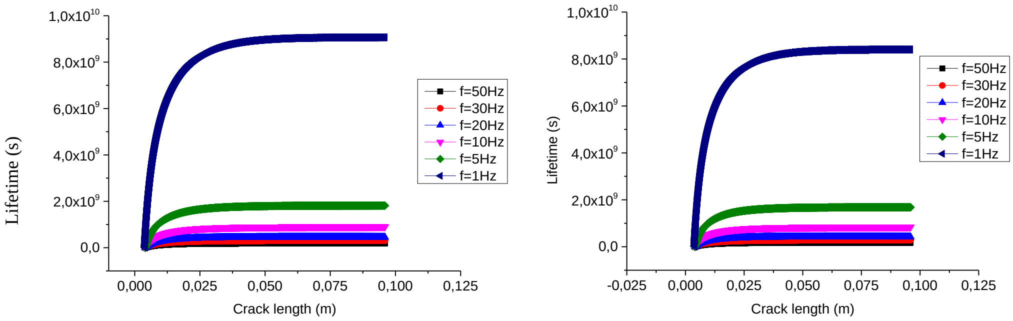

Fig. 12 (a,b):Influence of frequency. (a) Without overload, (b) With overload

In the Figure below we suggest the value of frequency is 1 Hz and we found that the lifetime of wheelset increases when the overload decreases. In the case f = 1Hz a bigger increase of the lifetime is gained $6.5672*10^8$ s.

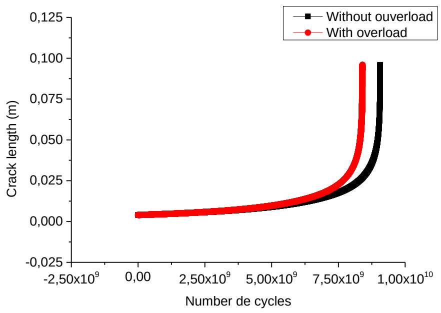

Fig. 13: Variation of lifetime.

5. Conclusion

The paper studies the influence of overload on the crack propagation velocity and the lifetime of wheelset with and without overload. It is shown that its influence is very important on the wheelset.

The results we obtained are the following:

- ✓ In the first case, fatigue life is very high comparing to the second one with the difference of $6.5672*10^8$ s.
- ✓ In the other case, we noticed that the frequency influence is very important especially in the case of a normal load.

Perceptively, we are going to decrease the crack growth by decreasing the frequency of wheelset by the reinforcement of the bogie damping system by improving its design.

Acknowledgments

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Nomenclature

ΔK: stress intensity factor.; K_c: Critical stress intensity factor.;
C: Paris coefficient ; n: Paris exponent ;
K_{Imax}: Maximal stress intensity factor.
K_{Imin}: Minimal stress intensity factor.; a:Crack length. N: Number on cycle.

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