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# THE EFFECT OF THRESHOLD VALUE ON THE RESIDUAL FATIGUE LIFETIME OF RAILWAY AXLES

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**Abstract:** *The fatigue failure of railway axles could have unaccepted consequences. Because of safe operation, it is important to determine the residual fatigue lifetime. The railway axle could contain some cracks either from manufacturing process or from previous service operation. Present defectoscopy can reliably detect only relatively long cracks (longer than 2 mm), see Zerbst et al. (2012). In other words, there is a risk that the existing crack is not detected by defectoscopy. For conservative establishment of the residual fatigue lifetime the crack, which could be not detected by defectoscopy, must be considered. This paper deals with an effect of the threshold value of fatigue crack propagation on the residual fatigue lifetime of railway axles. Two very commonly used materials for railway axles EA1N and EA4T steels are considered. The results of this paper could be used for safer operation of railway axles.*

**Keywords: Railway axle, Threshold value, Fatigue crack, Residual fatigue lifetime.**

## 1. Introduction

The railway axle is one of the most loaded parts of the whole train. Therefore, the residual fatigue lifetime of railway axle is significant for safe operation of the train. The place of the possible crack is assumed in the T-notch where equivalent stress reaches the maximum value, see Fig. 1. Fatigue crack grows perpendicular to the principal stress (Schijve, 2008) and according to (Ševčík et al., 2012) the shape of the crack is assumed to be semi-elliptical with changing ratios between semi-axis during fatigue crack growth. The fatigue crack propagation description is based on the stress intensity factor *K* approach, which is commonly used approach for establishing of the residual fatigue lifetimes of railway axles (Zerbst et al., 2012); (Madia et al., 2011). Predominantly loading of railway axle is caused by rotary bending, therefore, for the simplification only mode I of loading is considered.

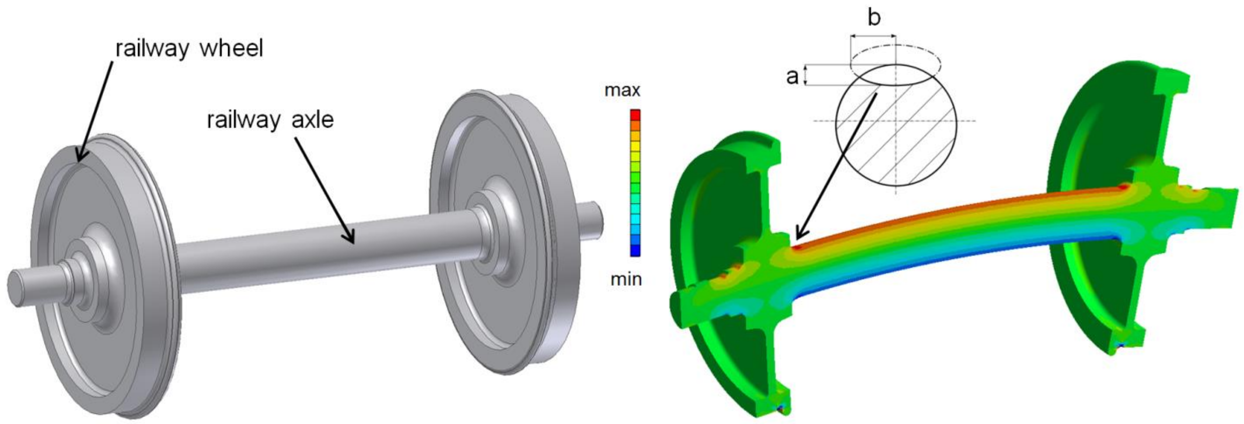


*Fig. 1: The railway axle with considered crack (Pokorný et al., 2014).*

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The stress intensity factor for mode I, $K_I$, is expressed as:

$$K_I = \sigma\sqrt{\pi a}Y_I(a), \tag{1}$$

where $Y_I$ is function including the influence of railway axle and crack geometry. This function in polynomial form was obtained according to (Ševčík et al., 2012) by FEM modeling, $a$ is crack length and $\sigma$ is remote loading stress. The railway axles are subjected to variable amplitude loading. Predominantly loading is caused by weight of the vehicle, but there are additional forces acting during train movement. These forces arise when the train goes through curved track, over crossovers, switches etc. For accurate estimation of the residual fatigue lifetime the representative railway axle loading is necessary to know. The representative axle loading is often obtained by strain gage measurement. The typical load spectrum (sorted by Rain-flow method) is shown in Fig. 2.

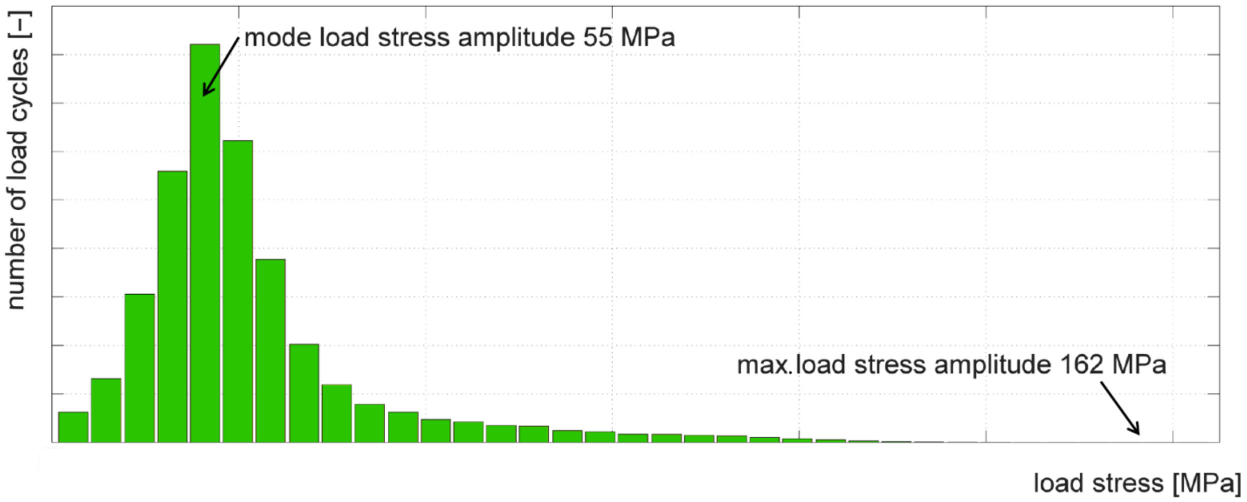


*Fig. 2: Histogram of railway axle load spectrum (sorted into 35 classes of load amplitudes).*

The place of considered crack is also influenced by press-fitted wheel, besides above mentioned railway axle load spectrum. The press-fit contributes to higher crack opening stress, so the total stress intensity factor $K_{tot}$ is given as:

$$K_{tot} = K_I + K_{I,pressfit}, \tag{2}$$

where $K_{I,pressfit}$ is an additional stress intensity factor caused by presence of press-fit.

The additional stress intensity factor $K_{I,pressfit}$ can be expressed by polynomial function in the form:

$$K_{I,pressfit} = c_0 + c_1 a + c_2 a^2 + c_3 a^3 + c_4 a^4 + c_5 a^5 + c_6 a^6, \tag{3}$$

where determination of constants $c_i$ is based on FEM modelling.

## 2. Estimation of the Residual Fatigue Lifetime

The residual fatigue lifetime is considered as number of cycles for crack growth from initial size to the critical one. For determination of number of cycles the Paris-Erdogan relationship is used:

$$\frac{da}{dN} = C(K_{tot})^m. \tag{4}$$

The crack increment is then obtained by integrating of Eq. 4. This equation is valid only for stress intensity factors greater than threshold value $K_{th}$. Otherwise, the increment of crack length is zero. Two very commonly used materials for railway axles, EA1N and EA4T steels, are assumed in this paper. Simplified v-K dependences of these materials are shown in Fig. 3.

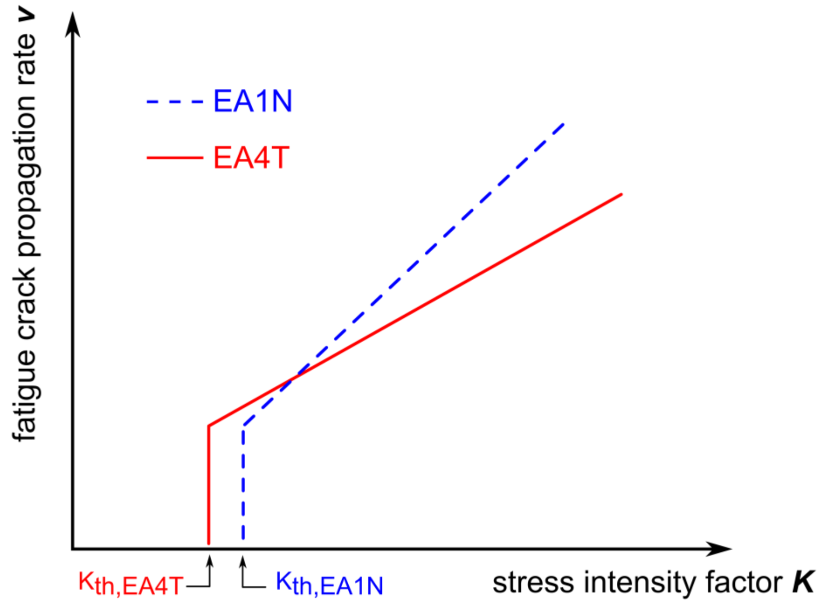


*Fig. 3: Simplified v-K curves of considered materials (log-log representation).*

### 2.1. Effect of different threshold values on the residual fatigue lifetime of railway axle

The threshold value is one of the most important inputs for establishing of the residual fatigue lifetimes of the railway axles. Although, the aim of manufactures is to produce material with the same chemical composition and mechanical properties, some scatter in material properties (e.g. threshold value $K_{th}$) between individual casts still exists. The next scatter is given by experimental establishment of threshold value $K_{th}$. Therefore, the determined residual fatigue lifetime could be different from the reality. Tab. 1 shows determined fatigue lifetimes for different threshold values $K_{th}$ of EA4T steel. In case of initial crack length 1 mm the effect of different threshold value is greater than in case of initial crack length 2 mm. The EA1N is more sensitive on threshold value $K_{th}$ than steel EA4T, see Tab. 2. For instance, the difference between $K_{th} = 6.8\ MPa\sqrt{m}$ and $K_{th} = 7.0\ MPa\sqrt{m}$ leads to residual fatigue lifetimes *1 481 000 km* and *3 275 000 km*, respectively. This implies that the incorrectly established threshold value by 3% leads to less than half of the original residual fatigue lifetime in this particular case.

*Tab. 1: Residual fatigue lifetime in thousands of km for different considered threshold values (EA4T).*

| **material EA4T** | | | | | | | |
|---|---|---|---|---|---|---|---|
| considered $K_{th}$ $[MPa\sqrt{m}]$ | 5 | 5.5 | 5.8 | **6*** | 6.2 | 6.5 | 7 |
| thousands of km for fatigue crack growth from *1 mm to 55 mm* | 66 | 85 | 105 | **128** | 172 | 355 | 2 332 |
| thousands of km for fatigue crack growth from *2 mm to 55 mm* | 46 | 50 | 54 | **58** | 63 | 71 | 93 |

*Tab. 2: Residual fatigue lifetime in thousands of km for different considered threshold values (EA1N).*

| **material EA1N** | | | | | | | |
|---|---|---|---|---|---|---|---|
| considered $K_{th}$ $[MPa\sqrt{m}]$ | 6 | 6.5 | 6.8 | **7*** | 7.2 | 7.5 | 8 |
| thousands of km for fatigue crack growth from *1 mm to 55 mm* | 187 | 525 | 1 481 | **3 275** | 7 141 | 27 807 | infinity |
| thousands of km for fatigue crack growth from *2 mm to 55 mm* | 68 | 82 | 94 | **104** | 116 | 142 | 240 |

* *considered real mean threshold values*

## 3. Discussion

The Fig. 4 shows evolution of threshold stress (stress expressed from Eq. 2 with substitution $K_{tot} = K_{th}$) in dependence on the crack length a. For initial crack lengths 1 mm and 2 mm respectively, many load stress amplitudes are under threshold value. According to Fig. 2 the mode load stress amplitude is 55 MPa. This stress corresponds to load by static weight of vehicle. However, stress amplitude 55 MPa gets over threshold value for cracks longer than 10 mm, see Fig. 4. Therefore, just only the several highest classes of load amplitudes (from histogram in Fig. 2) contribute to crack elongation for initial crack lengths 1 mm or 2 mm.

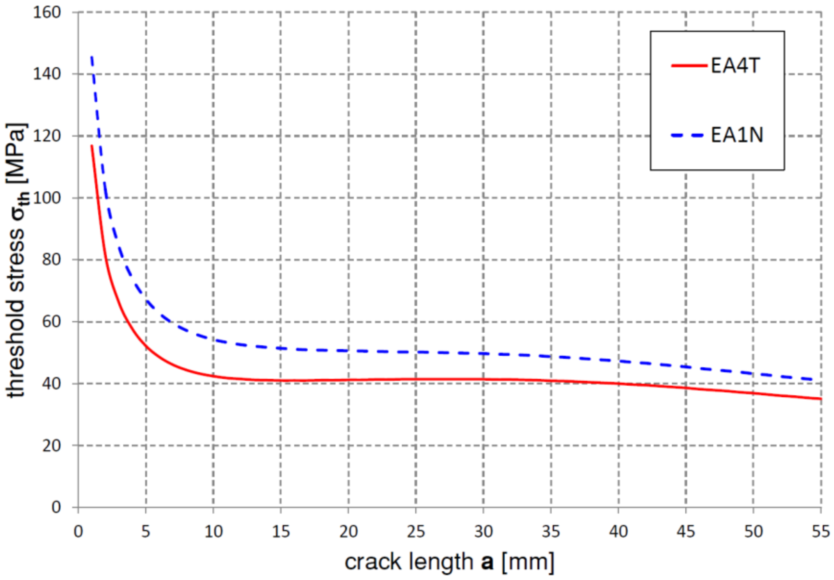


*Fig. 4: Threshold stress* $\boldsymbol{\sigma_{th}}$ *in dependence on the crack length a.*

## 4. Conclusions

This paper shows that threshold value is important input for estimation of the residual fatigue lifetime. Several computations with real and fictitious threshold values were carried out. The aim of this paper is to show difference between considered accurate threshold value and threshold values more or less deflecting of considered accurate one. The determined residual fatigue lifetimes exhibit relatively high sensitivity on accuracy of threshold values. This effect is more pronounced for material EA1N than for material EA4T. This sensitivity is smaller for longer cracks, see Tab.1 and Tab. 2. Therefore, the highest sensitivity is for railway axles made of EA1N steel with smaller initial crack. It follows that for accurate estimation of the residual fatigue lifetime the threshold value should be determined as precisely as it is possible.

Results obtained could be beneficial for better understanding of fatigue crack behavior in the railway axles.


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