APPLIED MECHANICS 2018

April 9 - 11, 2018, Myslovice, Czech republic

SENSITIVITY ANALYSIS OF THE CRACK EVALUATION FOR STEAM TURBINE CASINGS LOADED BY PRESSURE AND TEMPERATURES

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Abstract: The operation of steam turbines is related to the extreme conditions such as high pressure and temperature, which can lead to fatigue issues and subsequent undesirable problems. This paper is focused on the methodology for the fracture analysis of turbine casings. The evaluation methodology is based on so called Failure Assessment Diagram and preceding stress analysis. Stress field is calculated for steady operation conditions (creep) and for non-stationary temperature and pressure loading (run-ups) using the finite element method. Afterwards it is used for the evaluation of crack distribution. The fracture analysis is affected by number of inputs parameters, such as material definition, geometry, loading history (set of starts under different temperatures), initial crack size, shape etc. This paper assess the effect of the input parameter variation on the crack growth calculation.

Keywords: crack, sensitivity analysis, Fitness for Service

1 Introduction

Steam turbines are the crucial elements of the power plants. Their operation is related to extreme conditions such as high pressure and high temperature. Consequently, the extreme mechanical loading can lead to fatigue issues and subsequent undesirable troubles of the particular segments. The fatigue assessment of turbine casings during the turbine operation is therefore significant process, which can help with the decision on further operation, reparation or putting casing out of the operation.

General overview and verification of Fitness for Service methodology is presented in [1]. Bakić uses in his work [2] non-destructive testing methods and calculation of exhaustion levels and critical crack size in case of a high-pressure turbine casing. The results of finite element method calculation for creep and thermal loading are employed. Their remaining life assessment methodology is based on the rule of life fractions (combination of Miner's and Robinson's rule). Hakl [3] presents residual life assessment of particular turbine casing with existing crack defects. He uses both experimental and theoretical analysis in order to estimate safe turbine operation. The evaluation of fracture mechanics parameters using the finite element method in case of thermal induced flaws is described in [4]. Creep fatigue and related stress intensity factors are studied in [5].

This paper deals with the methodology for the fracture and fatigue analysis of turbine casings based on so called Fitness for Service methodology (FFS). At first, methodology is very briefly summarized. Secondly, the stress distribution is calculated for steady operation conditions (creep) and for non-stationary temperature and pressure loading (run-ups) for a chosen testing example. This is further used for the evaluation of cracks analysis. The sensitivity of the crack growth on the inputs parameters is being tested with the variation of the particular parameters and comparison of such changes on the final results. Such sensitivity analysis can lead to a better understanding of the effect of the initial inputs, which might not be always easy to determine.

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2 Methodology overview

FFS assessment is a multi-disciplinary engineering approach used to determine if casing (or generally some equipment) is acceptable to continue operation. It is based on common API579-1/ASME Standard [6] and British Standard [7]. The overall scheme of the methodology for the evaluation of existing flaw acceptance is presented in Fig. 1.

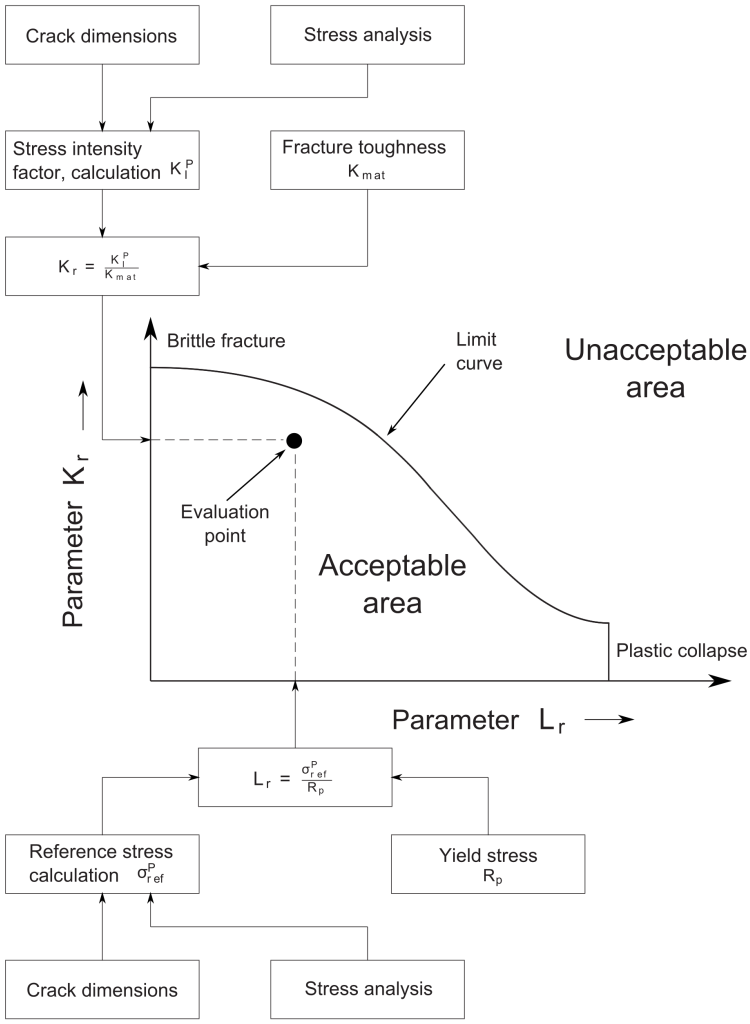

Figure 1: Flowchart of the evaluation methodology for the particular flaw analysis.

Load ratio L_r and toughness ratio K_r determine the position (evaluation point) in the Failure Assessment Diagram that is related to the limit curve dividing the diagram into acceptable and unacceptable areas. The proximity of the evaluation point to the limit curve means risky operation with the evaluated defect. The parameters can be expressed using the ratios as:

$$L_r = \frac{\sigma_{ref}}{R_p}, \qquad K_r = \frac{K_l}{K_{mat}}, \tag{1}$$

where σ_{ref} is the reference stress, R_p is the yield stress, K_l is the stress intensity factor for particular crack and K_{mat} is the fracture toughness. Detailed methodlogy description is presented in [9].

Large set of material parameters and constants has to be known in order to have enough information for the crack acceptance assessment. These parameters are determined from the experiments or from material databases or tables included in the standards. For more information on the developed methodology see also [8].

3 Definition of a chosen case study

The aim of this study is to perform a brief sensitivity analysis of one particular crack under defined loading, loading history and with G17CrMoV5-10 material (common material in the power plant steam turbine and chassis). The example here consists of infinite longitudinal crack which can be located from outside (Fig. 2) or inside (Fig.3) surface.

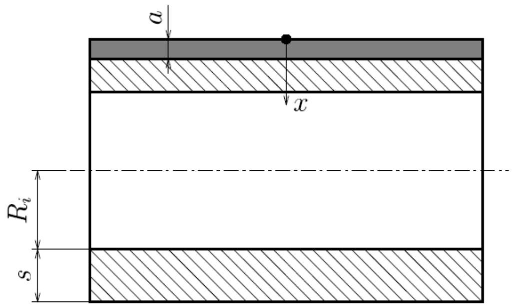

Figure 2: Infinite length crack from outer surface

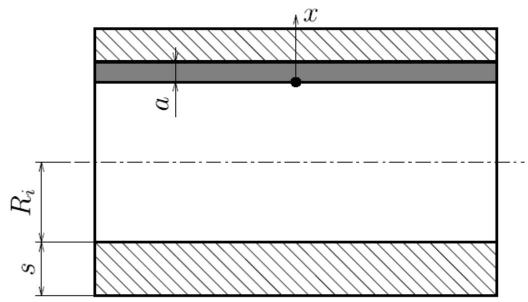

Figure 3: Infinite length crack from inner surface

The proper definition of the problem requires large number of parameters which could be sometimes inaccurate or unknown. The effort here is to test the effect of the material parameter variations on the verification of Fitness for Service methodology. Consequently, four parameters of the material definition are varied between their upper (U), middle (M) and lower (L) values, namely:

- K_{CSR} — Speed of the Creep Deformation
- K_{pt} — Creep Strength
- $\frac{da}{dt}$ — Material parameter, from database
- $K_{fcg} = \frac{da}{dN}$ — Speed of the Crack Growing during Creep and Fatigue

Particular limit values of these parameters are shown in Table 1.

Parameter	Lower (L)	Middle (M)	Upper (U)	Description
K_{CSR}	8e-1	1	1.25	Speed of the Creep Deformation
K_{pt}	1.25	1	0.5	Creep Strength
$\frac{da}{dt}$	0.006	0.06	0.6	Material parameter
$K_{fcg} = \frac{da}{dN}$	1	1.1	-1.25	Speed of the Crack Growing

Table 1: Material parameters definition for the sensitivity analysis

4 Sensitivity analysis

This section includes the results of parametric studies on the proposed crack evaluation methodology. Ten different settings of such parameters were evaluated. The set of case studies are listed in Tab. 2.

	K_{CSR}	K_{pt}	$\frac{da}{dt}$	K_{fcg}
MMML	M	M	M	L
LMUU	L	M	U	U
MLML	M	L	M	L
ULML	U	L	M	L
LLUU	L	L	U	U
UUUU	U	U	U	U
LLLL	L	L	L	L
UMLU	U	M	L	U
MUUM	M	U	U	M
LUMU	L	U	M	U

Table 2: Cases for sensitivity analysis, based on the parameter initial setting

4.1 FAD

Firstly, the algorithm evaluates Failure Assessment Diagram (FAD) for various safety factors called PSF_s. This value is defined by the user and typically has value between 1 and 2. Here, the values $1, 1.2, 1.4$ and 1.7 were tested. The flowchart on Fig. 1 indicates the particular steps of the FFS analysis.

Consequently, the total Failure Assessment Diagram (FAD), the relationship between the K_r and the L_r can be evaluated with the following graph, where black solid line is the critical limit curve between acceptable and unacceptable area, see Fig. 4. Note that the curves are plotted only upto this limit, but the calculation was done over this critical limit.

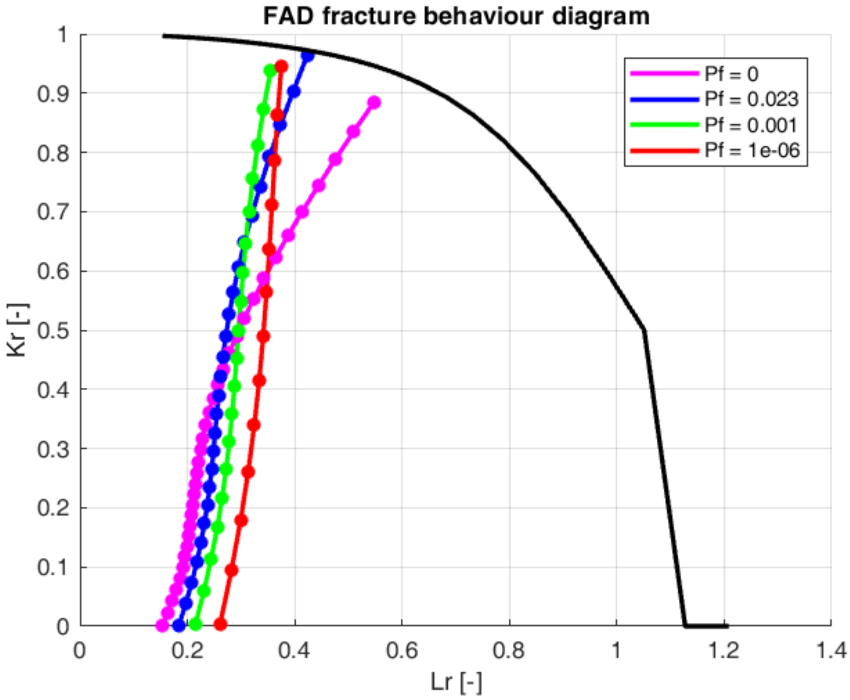

Figure 4: FAD - Failure Assessment Diagram

4.2 CCG - Crack growth

The crack growth propagation is demonstrated on testing tube example having the infinite length crack from the outside surface, of the initial depth a_0 equalling 5.0 mm, with the following geometry, material and loads, see Table 3.

Material	G17CrMoV5-10-1
Outer diameter d_0 [mm]	600
Wall thickness [mm]	50
Operating temperature °C	550
Time of the crack detection [h]	8500
Initial crack depth [mm]	5.0
Presumed operating time [h]	100 000
Number of hot run-ups [-]	12 500
Number of cold run-ups [-]	2500

Table 3: Geometry, loads and material properties of the testing body

The CCG algorithm is deeply described in the [8] and [9] and thus it will not be assessed here. The four parameters defined above, and their variations gives the following results of the crack growth propagation for all ten cases of the study:

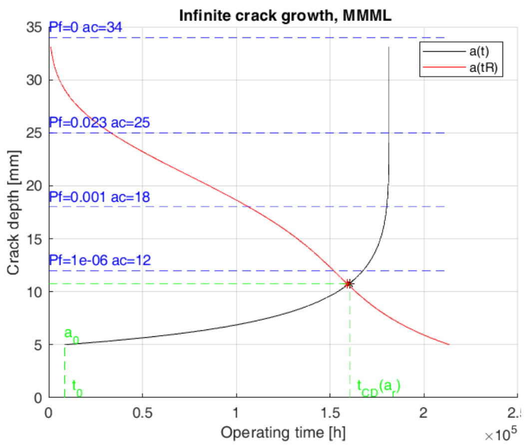

Figure 5: MMML

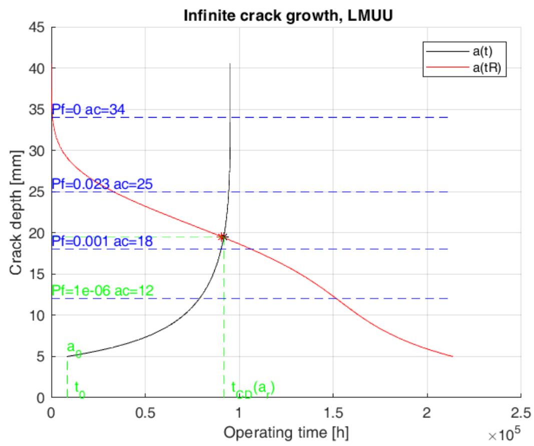

Figure 6: LMUU

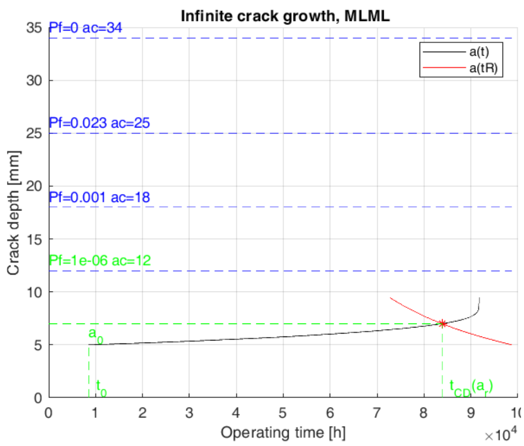

Figure 7: MLML

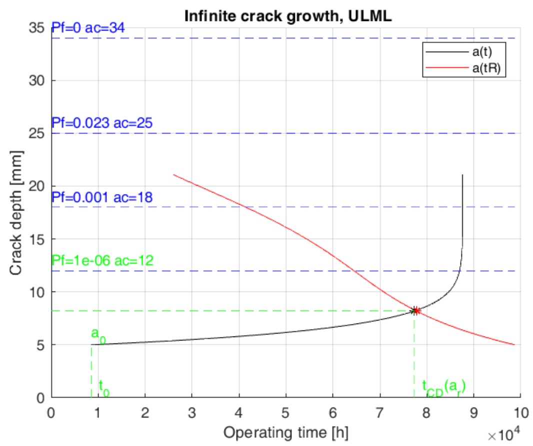

Figure 8: ULML

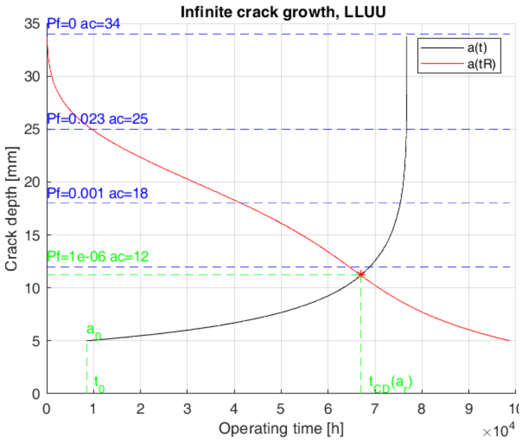

Figure 9: LLUU

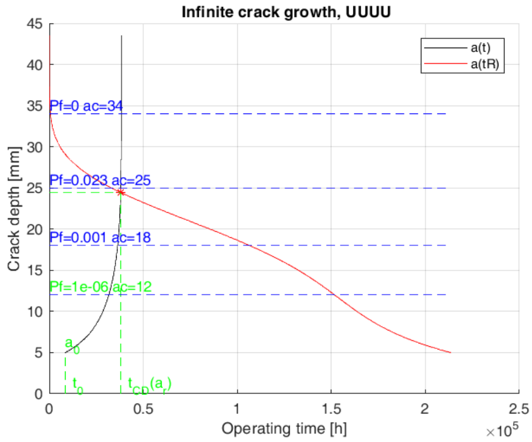

Figure 10: UUUU

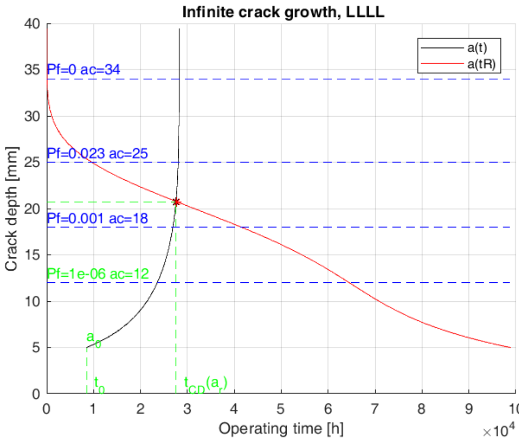

Figure 11: LLLL

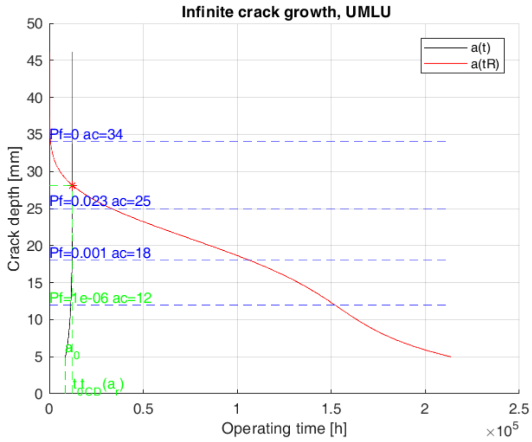

Figure 12: UMLU

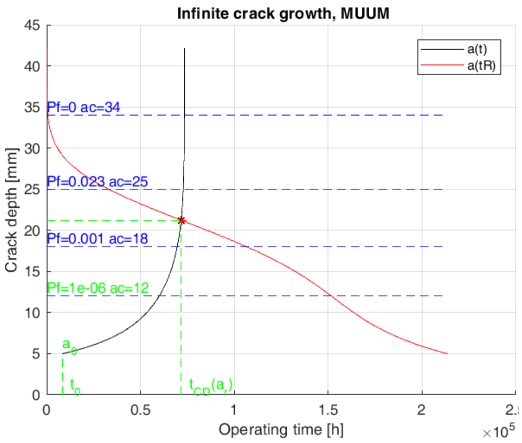

Figure 13: MUUM

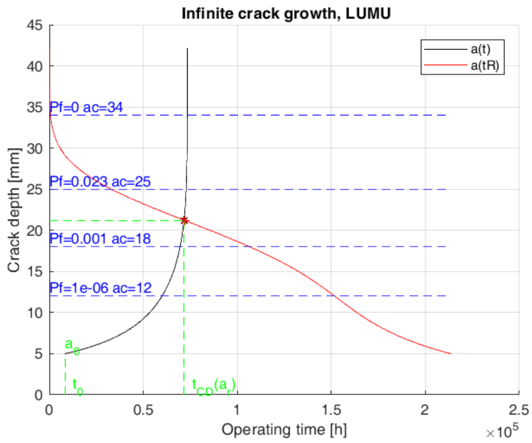

Figure 14: LUMU

The graphs in Figs. 7-14 show the increase of the crack depth with respect to the operating time. The black solid curve is the dependency of the crack depth on the operating time and the red solid line represents the crack depth versus time to failure. Further valuable results could be found e.g in the plot of the creep damage, Fig. 15, or the increase of the crack depth from the cold and hot run-ups, see Fig. 16.

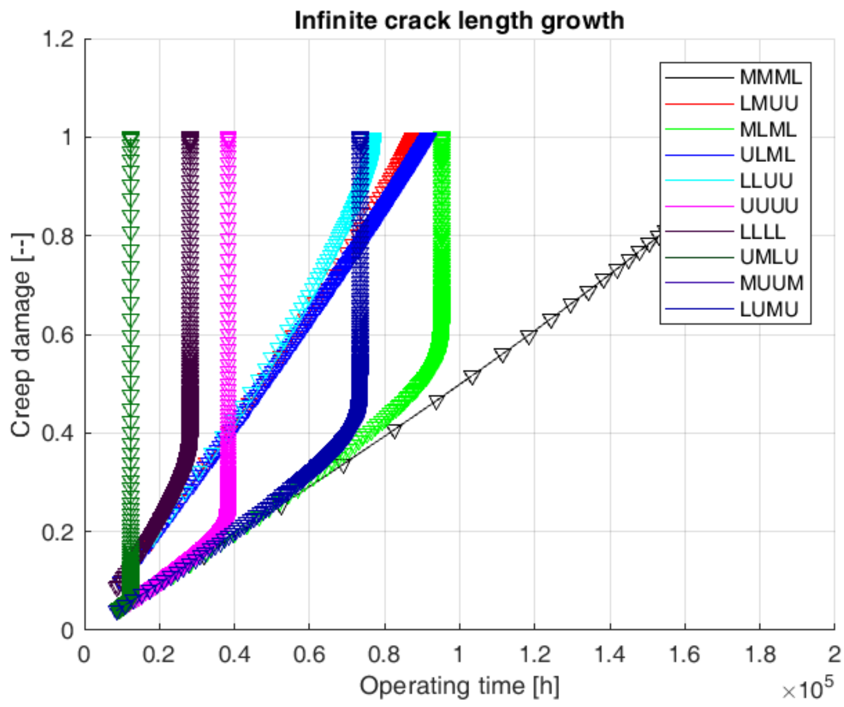

Figure 15: Effect of the initial material parameters on the Creep damage during operating time

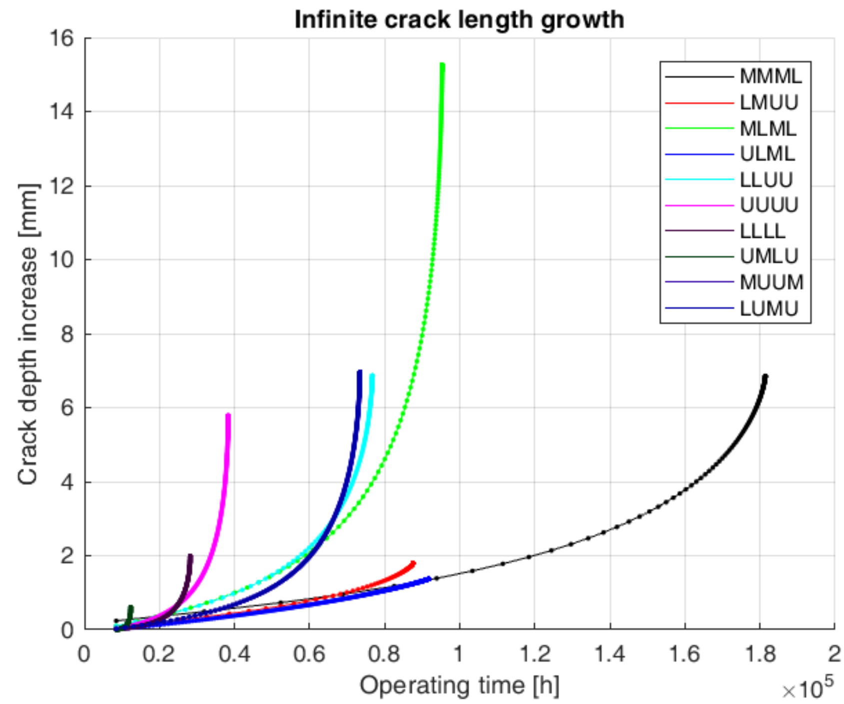

Figure 16: Effect of the initial material parameters on the crack propagation during operating time generated by the hot and cold run-ups

5 Discussion

The tested initial values of the particular parameters show their significant effect of the prediction of the crack growth. These parameters vary only between Upper, Medium and Lower values. Together, there were ten different configurations of these four parameters. The particular setting of these values are not always very well known and thus the estimation cannot be very straightforward. Results of this study gives us the overview, how important is the proper initial definition of all the quantities. All ten cases of the study used the same material parameters, the same FEM analysis results, the same loading history etc. Only these four quantities (Speed of the Creep Deformation, Creep Strength, da/dt and Speed of the Crack Growing during creep and Fatigue)change. However, the estimation of the crack growth changes significantly, see Figs. 15 - 16.

6 Conclusion

Analysis of the crack growth is a very complex problem required number of finite element analysis, proper description of the loading, material, geometry of the specimen as well as the crack, including number of particular parameters and their initial estimation. The study here is focused on the testing of the effect of the initial values change, required for the FFS assessment. Here, only four variables(K_{CSR}: Speed of the Creep Deformation, K_{pt}: Creep Strength, K_{fcg}: Speed of the crack growing during creep and fatigue and $\frac{da}{dt}$) were varied between their lower, medium and upper limits. Overall, 10 different configurations of the initial setting and the crack growth (depth or creep damage) were evaluated.

The achieved results indicate that the overall crack estimation is very sensitive on the initial setting of the input parameters. Only one small difference of one parameter can significantly increase or decrease the estimated crack depth. Consequently the user must be very thoughtful when defining the initial settings.

Acknowledgement

The paper has originated in the framework of institutional support for the long-time conception development of the research institution provided by the Ministry of Industry and Trade of the Czech Republic.

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