NUMERICAL ANALYSIS OF LIFE OF NOTCHED SPECIMENS SUBJECTED TO COMPLEX BENDING WITH TORSION

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Abstract. The authors analyzed life of specimens with rectangular sections and with notches (crack initiators). The specimens were loaded by amplitudes of bending and torsional moments, M_g and M_s respectively. The analysis was performed with use of the finite element method and the MSC Patran program using a modulus for fatigue calculations Fatigue. The analysis was done in order to select amplitudes of torsional and bending loading and determine fatigue life of the specimens made of 18G2A steel.

1. Introduction

Fatigue life determines a work time after which the element is subjected to failure. It includes the crack initiation period [10] and the fatigue crack propagation [6,7,11]. Relationships describing the crack growth rate after integration are usually applied for description of fatigue life including the crack propagation period [9,6,11]. Because of complexity of these relationships, integration is usually performed in a numerical way [8,11].

Numerical methods, for example the finite element method or the boundary element method [1,4] allow to perform a three-dimensional analysis of the stress and strain state in structural elements including a fatigue crack. These methods are also applied in order to accelerate design of machine elements, specimens for fatigue life tests and so on.

Numerical analysis of fatigue life prediction concerned specimens subjected to plane bending with torsion. Calculations were performed with the finite element method and the MSC Patran program, the fatigue calculation modulus Fatigue was also used [2]. A model of the specimen with the central sharp notch – a fatigue crack initiator is shown in Fig. 1 [5].

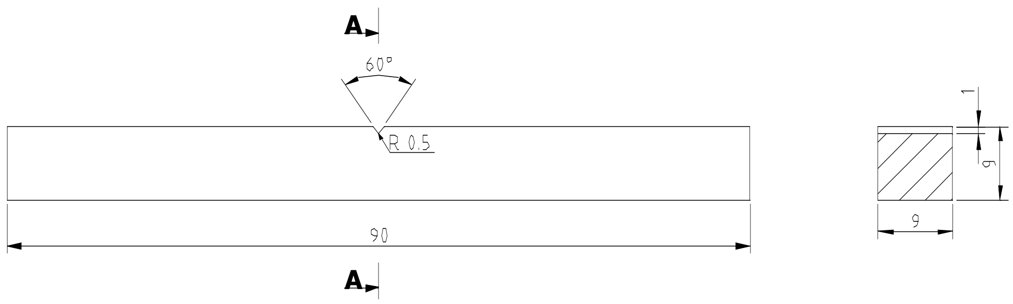

Fig.1 Shape and dimensions of the assumed specimens

Numerical analysis includes calculations of fatigue life of notched specimens for values of the torsional moments equal to 25%, 50%, 75% of nominal value of the bending moment. It was assumed that the specimen was made of low-alloy weldable general-purpose steel, resistant to atmospheric corrosion [3]. Mechanical properties of the considered steel are given in Table 1

Table 1 Mechanical properties of the considered steel

Material	Re [MPa]	RM [MPa]	A_{10} [%]	E [GPa]	ν
18G2A	357	535	21	210	0.3

2. The test stand

The machine MZGS-100 Ph is the basic element of the test stand. It can be applied for fatigue tests of constructional materials under biaxial cyclic stress with an optional angle of phase displacement between stresses caused by bending and torsion in the specimen cross-section [5].

At the stand the specimen can be loaded by any combination of bending and torsional moments, sinusoidally variable with the same frequency and the given phase displacement angle φ between the courses of both moments. The machine and its structure are shown in Figs. 2 and 3.

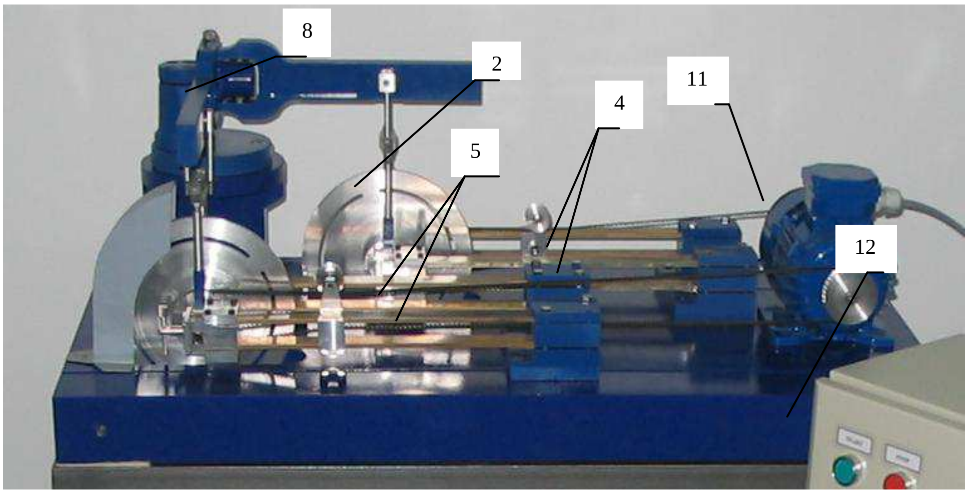

Fig. 2 The test stand where: 2- inertia vibrator, 4,5- strings, 8- specimen clamping, 11- electric motor, 12- control system

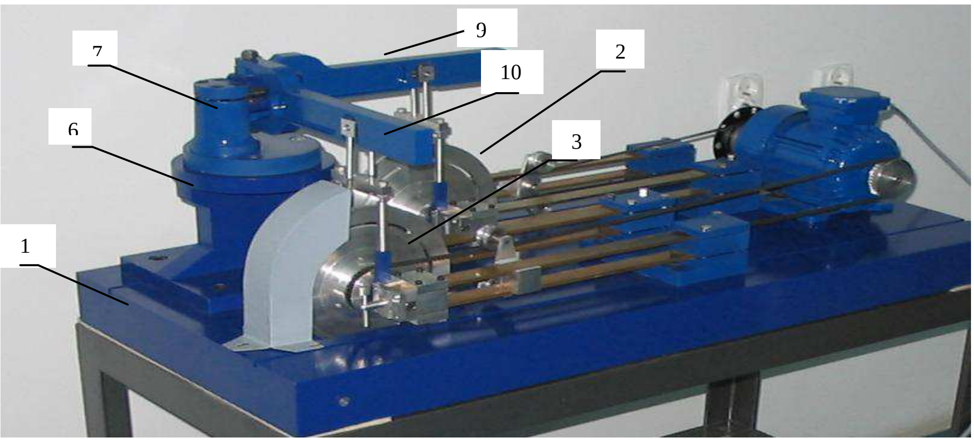

Fig. 3 The test stand where: 1- cast iron plate, 2,3- inertia vibrator, 6- base, 7- head, 9,10- levers,

3. Numerical calculations

Numerical analysis was realized with use of the MSC Patran program and the modulus for fatigue calculations Fatigue [4].

The following loadings were assumed for numerical calculations:
- under bending with torsion, amplitude of the bending moment was always M_{ag} = 16 Nm,
- amplitude of the torsional moment M_{as} was equal to 25%, 50%, and 75% of amplitude of the bending moment, i.e. the values were M_{as}= 4 Nm, M_{as}= 8 Nm and M_{as}= 12 Nm.

The phase displacement angle was always φ= 0 deg.. Fig. 4 shows the modelled specimen.

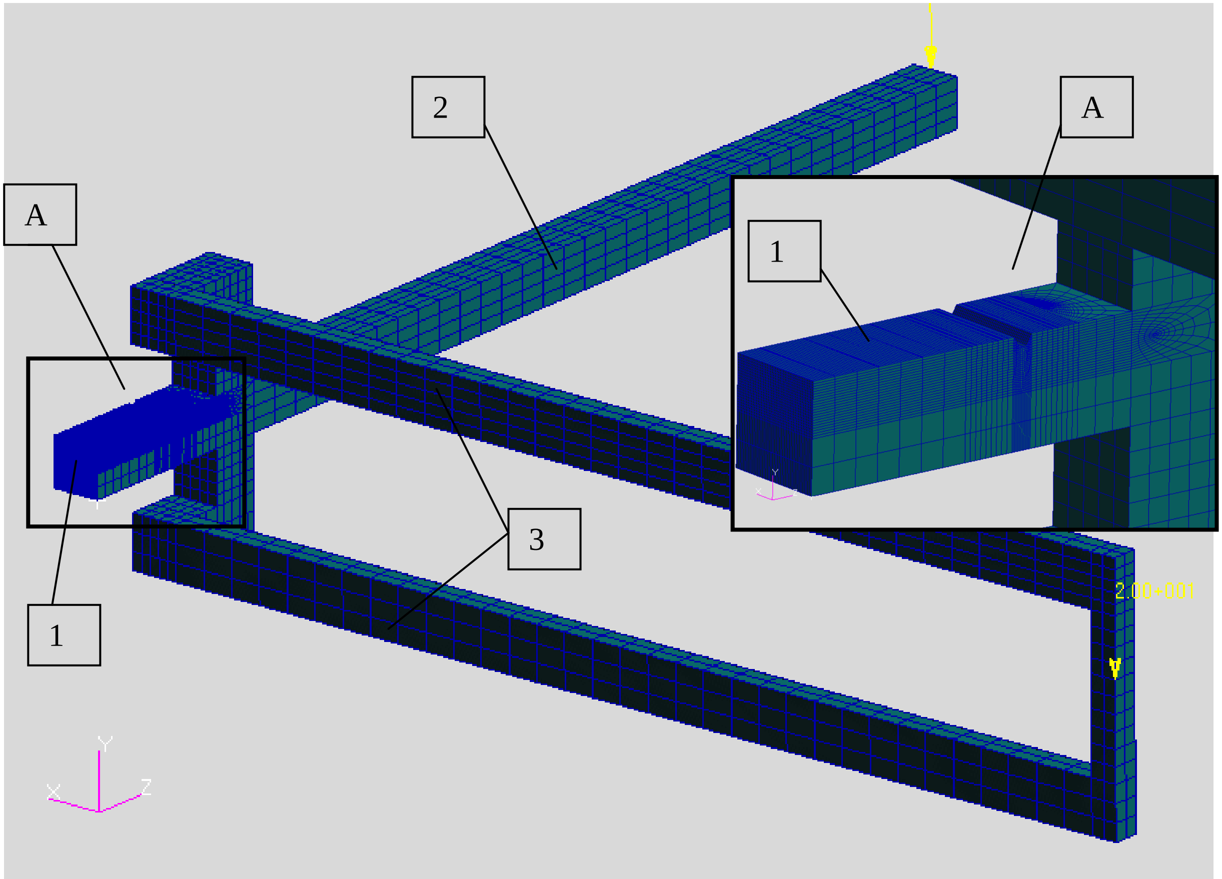

Fig. 4 Model of specimen, where 1- specimen, 2- bending arm, 3- torsional arm

Fig. 5 shows an exemplary map of life under loading by amplitude of the bending moment M_{ag}= 16 Nm and amplitude of the torsional moment M_{as}= 4 Nm. In Fig. 6 the above amplitudes of moments were: M_{ag}= 16 Nm i M_{as}= 8 Nm, and in Fig. 7 M_{ag}= 16 Nm and M_{as}= 8 Nm. The least calculated life was found in the plece of notch (crack initiator). The calculations were performed according to the SWT analysis [4], with Neuber's plastic correction for the level of confidence 50%. The program included influence of maximum principal stresses calculated while static analysis.

The specimen model includes 50350 six-node elements of Hex type, i.e. 55303 nodes. All the elements were hexagonal [4].

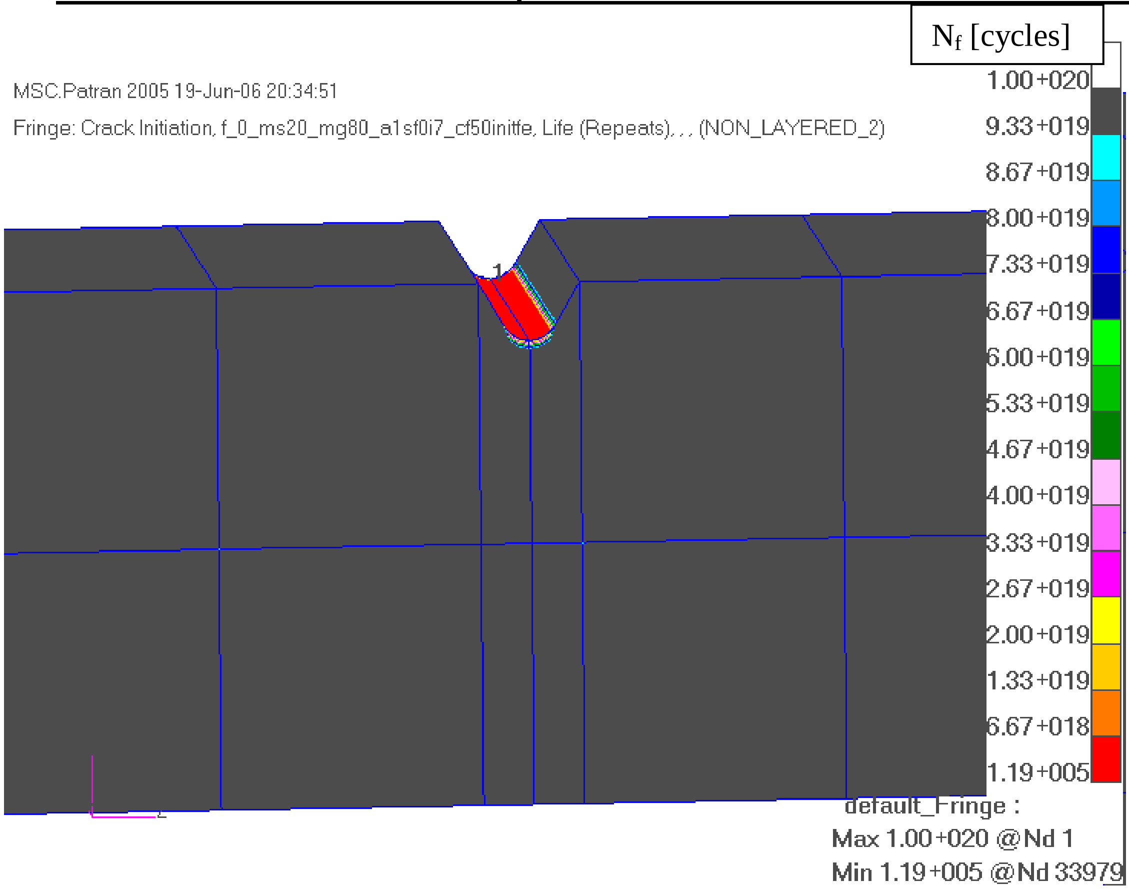

Fig. 5 Map of life N_f for M_g= 16 Nm and M_s = 4 Nm

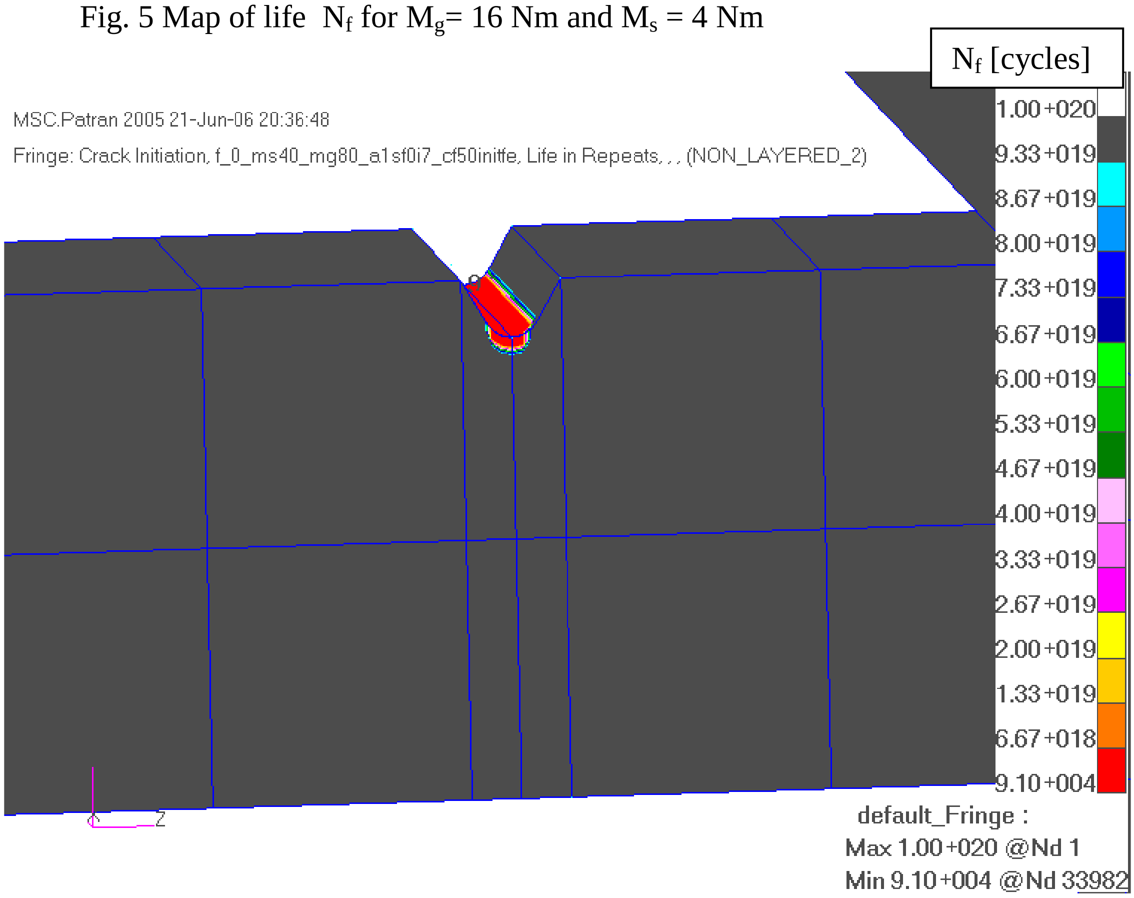

Fig. 6 Map of life N_f for M_g= 16 Nm i M_s = 8 Nm

N_f [cycles]

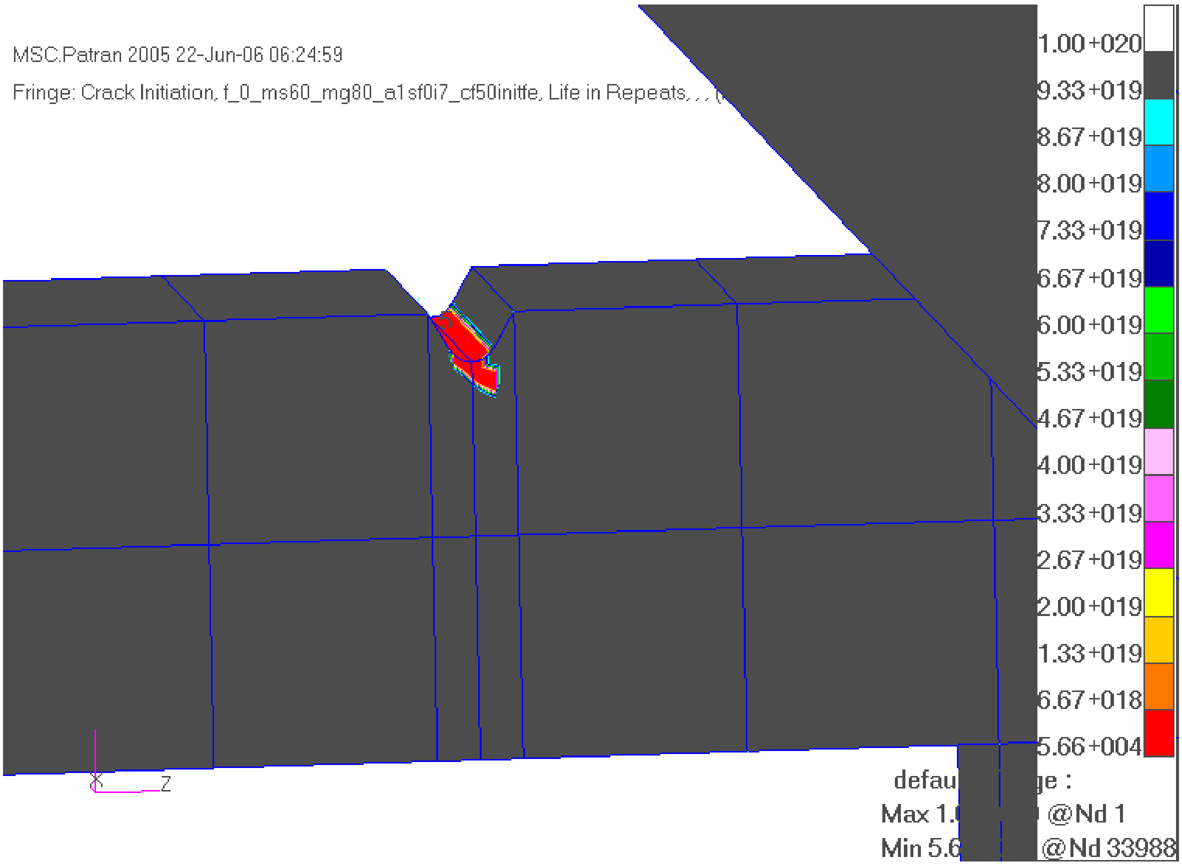

Fig. 7 Map of life N_f for M_g= 16 Nm i M_s = 12 Nm

4. Summary

From the numerical analysis it appears that the life for amplitude of the torsional moment M_{as} = 4 Nm is $N_f=1.19\cdot10^5$ cycles, for M_{as} = 8 Nm, $N_f=9.1\cdot10^4$ cycles, and for M_{as}=12 Nm N_f =$5.66\cdot10^4$ cycles. From the numerical calculations it also appears that as amplitude of the torsional moment rises, the life significantly decreases.

While tests of specimens at the stand MZGS-100 Ph for loading determined with the MSC Patran program, when amplitude of the bending moment was M_{ag}= 16 Nm, and amplitude of the torsional moment was M_{as} = 4 Nm we obtained $N_f=1.75\cdot10^5$ cycles.

The maximum difference between the specimen lives obtained from experiments and calculations for the assumed loading does not exceed 31%. Experimental verification of other loading cases has not been performed yet. It should be done while future stages of experiments.

5. Conclusions

From the numerical calculations and tests we can draw the following conclusions:

1. The MSC Patran program with the modulus Fatigue can be applied for determination of suitable values of specimen loading, which are used while tests.
2. The applied method of numerical calculations allows to obtain a map of lives of specimens loaded by amplitudes of bending and torsional moments.
3. From the test results it appears that the maximum difference between calculated and experimental lives does not exceed 31 %.

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