SEECCM 2017

4th South-East European Conference on Computational Mechanics

03-04 July, Kragujevac, Serbia

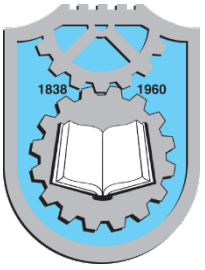
Organizers

Serbian Society for Computational Mechanics

Bioengineering Research and Development Center BioIRC

European Community on Computational Methods in Applied Sciences ECCOMAS

Department of Technical Sciences Serbian Academy of Sciences and Arts



Faculty of Engineering University of Kragujevac

Ministry of Education, Science and Technological Development of Republic of Serbia

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Contents

Welcome Address

Dear colleagues and students,

On behalf of the Organizing Committee, it is our great pleasure to welcome you to the 4th South East European Conference (SEECCM2017) in Kragujevac, Serbia.

The main objective of the SEECCM2017 is to summarize recent achievements in computational methods and their applications to industrial, technological and biomedical processes by bringing together leading scientists from all over the world and researchers from the South-East European (SEE) region. This goal is particularly important for the development in this field and motivation of young researchers and students in the SEE region.
The first SEECCM conference was held in 2006 in Kragujevac, Serbia and during this conference the Serbian Society for Computational Mechanics (SSCM) was founded. On the 10th-year anniversary of the SSCM we are happy to have new SEECCM conference in the same city. The previous three SEECCM conferences were successful and had a profound impact on the goals of the regional and the world community of scientists to invent and apply computational methods in the continuously increasing demands in science, technology and medicine. Today, Computational Mechanics is a very developed and integrative field which uses fundamental scientific laws and computer methods to study, predict and simulate material, engineering, physical, chemical and biomedical processes. Computer simulations are indispensable in testing hypotheses and assembling information in a quantitative context.

We have received more than 60 full papers and abstracts which were carefully reviewed before acceptance and we are thankful for such positive response. The topics of the papers fall into the area of: Solid Mechanics, Fracture Mechanics, Fluid Mechanics, Coupled Problems, Multiscale Modeling, Biomechanics, Nanomedicine, Cardiovascular Mechanics, Tissue Engineering, Dental Mechanics, Musculoskeletal Mechanics, Sport Biomechanics, Cellular and Molecular Mechanics, Medical Image Computing, Computational Chemistry, Medical Image Computing. The abstracts are included in this booklet, and some papers will be published in the Journal of the Serbian Society for Computational Mechanics, Vol. 11, Issue 1 – Special Issue – Proceedings of the 4th SEECCM, 2017.
We are delighted to announce the keynote speakers:

BURCZYNSKI Tadeusz | Institute of Fundamental Technological Research | Poland

ĐORĐEVIĆ Nenad | Brunel University London | UK

FERRARI Mauro | Houston Methodist Research Institute | USA

FOTIADIS Dimitrios | University of Ioannina | Greece

HELLMICH Christian | Institute for Mechanics of Materials and Structures | Austria

IBRAHIMBEGOVIĆ Adnan | University of Technology Compiègne | France

JEREMIĆ Boris | University of California at Davis | USA

KLEIN Erik | Slovak Technical University | Slovakia

MATTHIES Hermann | Braunschweig University of Technology | Germany

PEREGO Umberto | Polytechnic University of Milan | Italy

SCHREFLER Bernhard | University of Padova | Italy

We are thankful to the supporting organizations: Serbian Society for Computational Mechanics (the organizer) and our partners: Faculty of Engineering University of Kragujevac, Bioengineering R&D Center BIOIRC; and ECCOMASS and Serbian Academy of Sciences and Arts as auspice organizations. Also, we are thankful to the Organizing Committee and collaborators of BIOIRC and Faculty of Engineering for extraordinary efforts in solving many tasks regarding Conference preparation and support of the authors. We are grateful to the members of the Program and Scientific Committee for their dedication and support.

On behalf of the Organizing Committee we wish you a pleasant stay in the City of Kragujevac – in the heart of Serbia, and hope that you will be satisfied with the Conference achievements and enjoy Kragujevac's hospitality.

Conference Chairs:
Miloš Kojić, Manolis Papadrakakis and Nenad Filipović

Program at a Glance

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10:30 - 11:00	Keynote speaker – Prof. Umberto Perego	
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12:30 - 14:00	**Session M.2 Mechanics**	**Session M.3 Data Mining**
14:00 - 15:00	Buffet Lunch	
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Computational Chemistry
Mechanics
Biomechanics
Numerical Methods
Data Mining
Computational Biology
Finite Element Modelling

Technical Program

MONDAY, 03 JULY 2017

08:00 - 09:00	Registration

09:00 - 09:30	Opening Ceremony

09:30 - 10:00	Keynote speaker: **"Engineering Mechanics for Medicine and Biology: News on the "Cement Line" in Osteonal Bone."** **Prof. Christian Hellmich** *Institute for Mechanics of Materials and Structures, Austria*

10:00 - 10:30	Coffee Break

10:30 - 11:00	Keynote speaker: **"Simulation of fracture and delamination in layered shells due to blade cutting"** **Prof. Umberto Perego** *Polytechnic University of Milan, Italy*

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Chair: Velibor Isailović

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15:30 - 16:00	Keynote speaker: **"Computational models and Data – a Possible Fusion"** **Prof. Hermann Matthies** *Braunschweig University of Technology, Germany*

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17:30 - 18:00	Keynote speaker: **"Coupled Probability-Multiscale-Mechanics Method for Heterogeneous Composites: Formulation, Computations and Probability-Based Explanation of Size Effect"** **Prof. Adnan Ibrahimbegović** *University of Technology Compiègne, France*

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T.4.11 – *Lifetime Predictions of the Car-Carrying Wagon's Axle Guard*
Vladimir Milovanović, Gordana Jovičić, Miroslav Živković

18:30 - 19:00	Closing Ceremony

Book of Abstracts

Vulović, Milica Nikolić, Nenad Filipović

Human detects angular motion thanks to the excitation that is happening inside the semicircular canals (SCCs) of the inner ear. Afferent hair cells inside the SCCs are the ones that actually play the main role in detecting fluid flow inside those canals.
The present work briefly presents the mechanical and mathematical model behind the cupula membrane deformation during head rotation. Numerical solutions of the full model and a thorough analytical study of the linearized model reveal the principal mechanisms of canalithiasis.
Canalithiasis is a condition where small particles (small calcite particles, i.e. otoconias, syn. otoliths) disturb the flow in the SCCs. That can cause benign paroxysmal positional vertigo (top-shelf vertigo) and in our software we visualise the the membrane deformation for such conditions.

T.4.11 - *Lifetime Predictions of the Car-Carrying Wagon's Axle Guard* - Vladimir Milovanović, Gordana Jovičić, Miroslav Živković

This study focuses on the estimation of lifetime wagon structure's mechanical part. The mechanical part chosen for this investigation is an axle guard of running gear elements of the Hccrrs 2x2 axle car-carrying wagon. The observed axle guard is exposed to low cycle fatigue. Lifetime estimation procedure, based upon experimental and numerical methods has been introduced and applied. A complete cyclic characterization of the material is obtained, including new experimental ε–N fatigue curves for uniaxial tension–compression. The work has been developed using the experimental equipment and procedures available in Centre for engineering software and dynamic testing at Faculty of Engineering University of Kragujevac. According to the obtained experimental investigation and results performed by numerical calculations, the number of cycles until failure of axle guard is obtained.

75th Birthday of Miloš Kojić

This year (2017) we celebrate the 75th birthday of professor Miloš Kojić. Here are briefly presented his personal data and main scientific, professional and educational achievements.

Professor Kojić grew up in the village of Zakuta near Kragujevac, where he finished primary school and then high school in the city of Kragujevac. He graduated in 1964 from the Mechanical Engineering Department in Kragujevac (University of Belgrade), as the first in his generation, and completed MS studies at the Faculty of Natural Sciences of the University of Belgrade in 1969. He obtained his PhD degree in Mechanical Engineering from Rice University, Houston, in 1972.

The professional career of professor Kojić started in 1964, as an assistant for Mechanics at Mech Eng Dept in Kragujevac, and ended by retiring as a full professor in 2007. He was teaching various courses in Mechanics and Computational Methods at the undergraduate and graduate level at the University of Kragujevac, and others, including Univ Sarajevo and Belgrade Metropolitan University. He is the author of more than 10 textbooks.

He was a Visiting Scholar at Mech Eng Dept of MIT, a Research Scientist at Harvard School of Public Heath (10 years); a Research Engineer at ADINA R&D in Watertown, USA (4 years); and a Senior Scientist at Automobile Institute "Zastava" Kragujevac (1/3 of working time, 1975-1990). In 2006 he was elected as the first president of the Serbian Society for Computational Mechanics and the editor of the Journal of the Serbian Society for Computational Mechanics. From 2008 he serves as the director of the Bioengineering R&D Center BIOIRC, which he co-founded. From 2009 he serves as the Senior Member at Houston Methodist Research Institute. In 2009. he became a Corresponding Member of the Serbian Academy of Sciences and Arts.

The main research interest of professor Kojić is computational mechanics and the Finite Element Method in particular. He has over 250 publications, among which are a large number (~150) of scientific papers published in world leading journals. In the first period of his career his research was focused on nonlinear material problems in FEM, where he introduced the effective-stress-function, later generalized to governing parameter method for stress integration. His achievements were reported in a number of papers and summarized in the book: M. Kojić and K. J. Bathe, Inelastic Analysis of Solids and Structures, Springer, 2005. From 1995 his research was mainly oriented to bioengineering problems, particularly related to modeling nonlinear behavior of biologic materials. Results were published in various journals and summarized in the book: M. Kojić, N. Filipović, B. Stojanović, N. Kojić, Computer Modeling in Bioengineering, J. Wiley and Sons, 2008. More recently, from 2009, professor Kojić has been focused on the development of methods and software for modeling convective-diffusive transport of particles and molecules within the capillary system and tissues, particularly related to cancer. Here, he is leading the development of novel computational methodology, resulting finally into smeared models for general biomedical applications.

Professor Kojić is the founder and PI of the general-purpose FE program PAK (abbreviation in Serbian for Program for Structural Analysis), initiated in 1975. The PAK program is today composed of many moduli, including: structural analysis with geometrical and material nonlinearities (with large number of material models), fracture mechanics, field problems (fluid mechanics, heat transfer, flow through porous media), coupled problems (solid-fluid interaction, heat transfer and mechanics, flow through deformable porous media); biomechanics with tissue models, muscle

models, plaque growth models coupled with blood flow, convective-diffusive transport within capillary and tissue systems, multiscale hierarchical diffusion models, smeared models with composite finite element formulation. Based on the development of the computational methodology and PAK software (with modern pre-and post-processing) a large number of national and international (EU, USA) projects, as well as industrial, have been realized over the past several decades. Also, a significant number of MS and PhD theses (around 50) have been completed, and around 40 researchers are currently engaged in Kragujevac (University of Kragujevac – Faculty of Engineeing Sciences and Faculty of Sciences, and R&D Center BIOIRC) within several groups in the engineering and biomedical engineering fields. It can be said that a Serbian school of computational mechanics has been established in Kragujevac (currently with 15 professors and more than 30 researchers).

For his overall achievements in science, engineering, education and contribution to the Serbian society, a number of distinguished awards have been given to professor Kojić, including Diploma of the City of Kragujevac and Gold Medal of the Serbian Engineering Society.

Lifetime prediction of the car-carrying wagon's axle guard

Vladimir Milovanović[1*], Gordana Jovičić[2], Miroslav Živković[3]

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**corresponding author*

Abstract

This study focuses on the estimation of lifetime wagon structure's mechanical part. The mechanical part chosen for this investigation is an axle guard of running gear elements of the Hccrrs 2x2 axle car-carrying wagon. The observed axle guard is exposed to low cycle fatigue. Lifetime estimation procedure, based upon experimental and numerical methods has been introduced and applied. A complete cyclic characterization of the material is obtained, including new experimental ε–N fatigue curves for uniaxial tension–compression. The work has been developed using the experimental equipment and procedures available in Centre for engineering software and dynamic testing at Faculty of Engineering University of Kragujevac. According to the obtained experimental investigation and results performed by numerical calculations, the number of cycles until failure of axle guard is obtained.

Keywords: fatigue strength, ε–N method, lifetime estimate

1. Introduction

Fatigue analysis and lifetime evaluation are very important in design procedure to assure the safety and reliability of mechanical components. Many engineering components in different industries are operated in conditions in which they are subjected to low cycle fatigue at room and otherwise low or high temperatures. A significant number of papers have been devoted to finding a combined methodology for fatigue strength estimation of vital structural components made of different materials.

This paper presents the combined methodology for lifetime estimation of the vital structural component of the Hccrrs 2x2 axle car-carrying wagon. Developed methodology is based upon the experimental definition of fatigue parameters, defining the numerical model, numerical calculation of strength in accordance to corresponding standards and estimation of lifetime according to performed experimental and numerical results.

2. Technical data of the axle guard of running gear elements of Hccrrs 2x2 axle car-carrying wagon

The running gear basically contains wheel sets, a carrying suspension spring and suspensions. Axle guards are an integral part of the wheel set of twin-axle wagons and their primary role is to protect a free passage of the wagon in the curve, i.e. they are used for longitudinal and transverse guiding of the wheel set. The carrying parts of the running gear elements of the Hccrrs 2x2 axle car-carrying wagon are made of the S355J0 steel grade, while the material of the axle guard is the S355J2+N steel.

The primary role of the axle guards is to receive longitudinal forces in the processes of braking and accelerating and transverse forces in curves (especially when travelling through the "S" curve). When passing through the curve the role of the axle guard is to allow the axis rotation of the wheel set in relation to the longitudinal axis of the wagon. The structure of the axle guard significantly affects the ride quality of the wagon.

The considered axle guard of running gear elements of the Hccrrs 2x2 axle car-carrying wagon is a reinforced axle guard with constant stiffness (linear characteristics). It is exposed to low cycle fatigue and must meet requirements for static and fatigue loads according to the UIC 517 standard, point 3.1 and 3.2, Appendix L2 (Fig. 1.).

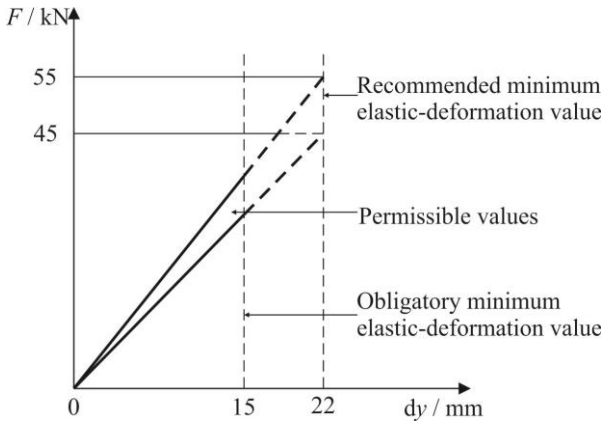

Fig. 1. Rigidity of axle guard with constant stiffness (reinforced type)

3. Fatigue material characterization

This section describes a complete fatigue characterization of S355J2+N steel grade, carried out according to the internal procedures of the Centre for engineering software and dynamic testing at Faculty of Engineering University of Kragujevac, based on the ASTM E468-90 and ASTM E606-92 standards.

Uniaxial tension–compression fatigue tests of the S355J2+N steel grade was done at room temperature ambient (23±5ºC) The material used in the test was S355J2+N steel grade with the monotonic mechanical properties (minimum yield stresses of 345 MPa, minimum tensile strength of 530 MPa, Young's modulus 2.1×10^5 MPa) for thicknesses above 16 mm.

Uniaxial tension–compression fatigue tests were performed by applying a sinusoidal wave in a universal servo-hydraulic machine SHIMADZU Servopulser EV101K3-070-0A, with 100 kN of axial maximum force. All specimens have finely polished to minimize surface roughness

effects. The tests were strain controlled by means of an SHIMADZU DYNASTRAIN TCK-1-LH dynamic extensometer with a ±1 mm working range.

The strain levels used to control the fatigue tests were chosen from the previously performed monotonic material characterization. The selection criteria were to obtain fatigue life cycles between 10^4 and 10^6 cycles. The uniaxial tension-compression test planning (loading ratio R=-1, i.e. mean strain amplitude ε_m=0%) is: five levels, three repetitions per level with a range of strain amplitude from 0.15% to 0.20%. The test frequency used in the characterization was in the range of 3–10 Hz, and the crack initiation criterion (failure criterion) was quick stiffness loss (load amplitude loss of about 10%).

Mathematical model used to describe fatigue behaviour of the S355J2+N steel grade from uniaxial tension–compression fatigue tests, i.e. σ-N cyclic curve, are created by taking Ramberg–Osgood's approach presented by equation (1). For description fatigue behaviour of the S355J2+N steel grade from uniaxial tension–compression fatigue tests, i.e. ε-N cyclic curve equation (2), as the sum of Basquin's and Manson-Coffin's, part was used.

$$\varepsilon_a = \frac{\Delta\varepsilon}{2} = \varepsilon_{a,e} + \varepsilon_{a,p} = \frac{\Delta\varepsilon_e}{2} + \frac{\Delta\varepsilon_p}{2} = \frac{\Delta\sigma}{2E} + \left(\frac{\Delta\sigma}{2K'}\right)^{\frac{1}{n'}} = \frac{\sigma_a}{E} + \left(\frac{\sigma_a}{K'}\right)^{\frac{1}{n'}} \tag{1}$$

$$\varepsilon_a = \frac{\Delta\varepsilon}{2} = \varepsilon_{a,e} + \varepsilon_{a,p} = \frac{\Delta\varepsilon_e}{2} + \frac{\Delta\varepsilon_p}{2} = \frac{\sigma'_f}{E}\left(2N_f\right)^b + \varepsilon'_f\left(2N_f\right)^c \tag{2}$$

Based on obtained experimental results and statistical analysis according to standard ASTM E739-91:2004, uniaxial tension–compression strain controlled mechanical properties of S355J2+N steel grade have been shown in Table 1.

Uniaxial cyclic properties	Value
Cyclic strength coefficient, K'	1470.45 MPa
Cyclic strain hardening exponent, n'	0.0234
Cyclic yield strength, σ_y'	342.65 MPa
Fatigue strength coefficient, σ_f'	575.25 MPa
Fatigue strength exponent, b	-0.0656
Fatigue ductility coefficient, ε_f'	0.0182
Fatigue ductility exponent, c	-0.2807

Table 1. Uniaxial tension–compression strain controlled mechanical properties of S355J2+N steel grade

According to experimentally obtained uniaxial tension–compression strain controlled mechanical properties of S355J2+N steel grade strain–life curve (log–log representation), have been determined and shown in Fig. 2.

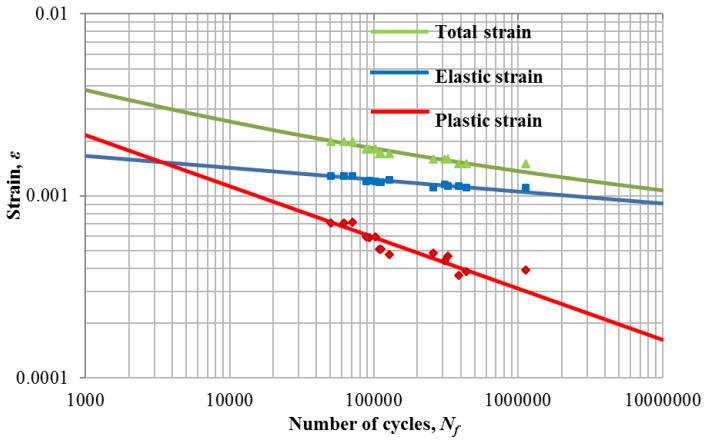

Fig. 2. Strain–life curve from uniaxial tension–compression strain controlled fatigue test of S355J2+N steel grade

4. Numerical calculation and lifetime estimation

4.1 Description of FEM model

The running gear elements of the Hccrrs 2x2 axle car-carrying wagon are modelled by using the Femap software with the NX Nastran solver, which is based on the finite element method. According to the design type, rectangular and triangular (four and three nodes, respectively) shell elements of appropriate thicknesses are used for creating a finite element mesh. The element length is approximately 40 mm. The 3D model of the running gear of the Hccrrs 2x2 axle car-carrying wagon with the axle guard is shown in Fig. 3.

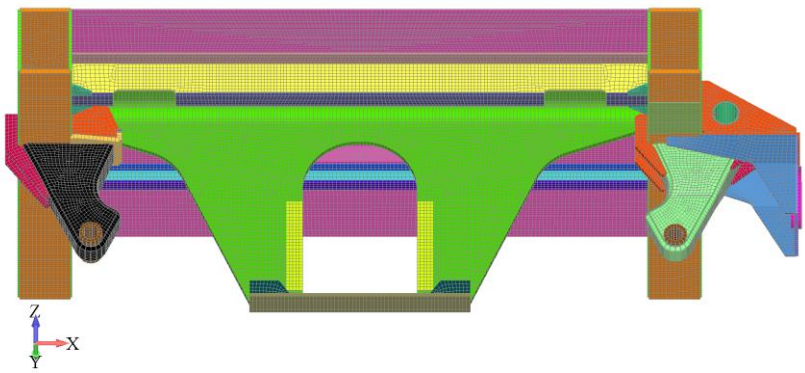

Fig. 3. 3D model of running gear of Hccrrs 2x2 axle car-carrying wagon with axle guard – finite element mesh

4.2 Elastoplastic analysis of axle guard in the case of lateral displacement of 22 mm

The most unfavorable load case in real conditions of exploitation was considered in the calculation of the fatigue strength of the axle guard. The most unfavorable load case is the case

when the wagon is loaded with maximum payload and passes through the curve with the minimum radius. The aim of the elastoplastic analysis of the axle guard is the determination of the plastic strain field. Number of cycles before damage can be determined based on the maximum value of the plastic strain. A scheme of the model loading in the case of the axle guard lateral displacement of 22 mm at the point of longitudinal force application, is shown in Fig. 4.

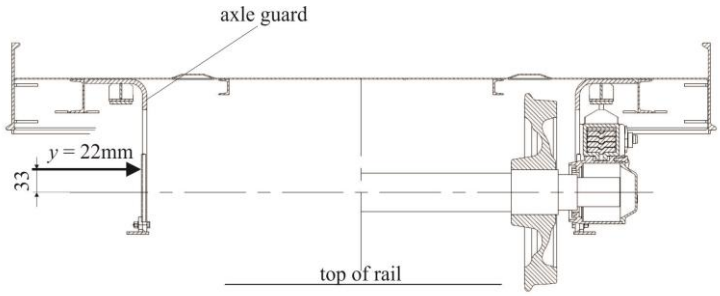

Fig. 4. Scheme of model loading; maximum lateral displacement y=22 mm

Based on the elastoplastic analysis the Von Mises equivalent stress field, the total strain field and plastic strain field were determined. The plastic strain field calculated using the elastoplastic analysis for the axle guard are shown in Fig.5.

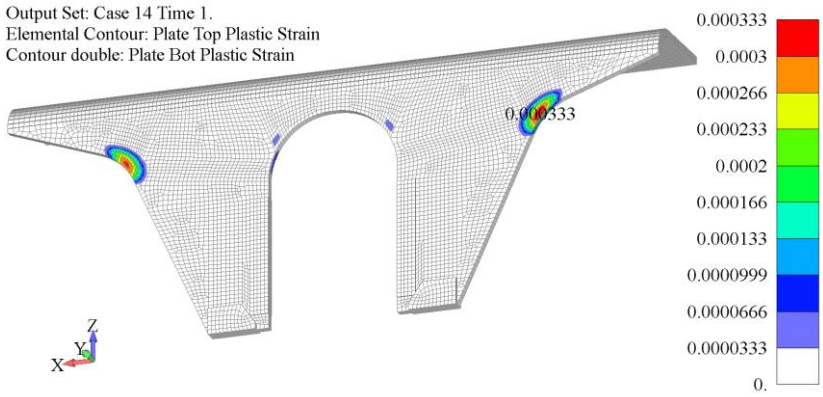

Fig. 5. The plastic strain field of axle guard – calculation results

According to the values of the plastic deformation of the axle guard and obtained fatigue material properties of S355J2+N, the number of cycles to failure is determined. The results shown in Fig. 6, present dependence of the number of cycles and plastic strain. For the considered axle guard, the obtained fatigue life reaches 775007 cycles. The focus of this analysis was to predict lifetime of axle guard according to maximal value of plastic strain and obtained fatigue material properties of S355J2+N.

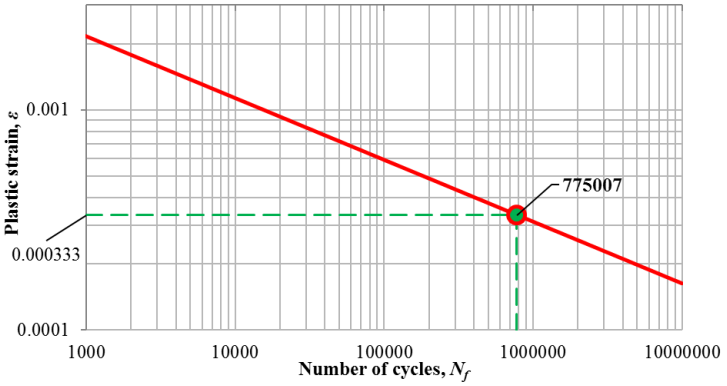

Fig. 7. Plastic strain-life curve of S355J2+N material obtained by calculation of axle guard

4. Conclusions

In this paper is presented the methodology for the evaluation of the structural integrity assessment of the axle guard of running gear elements of the Hccrrs 2x2 axle car-carrying wagon exposed to a low cycle fatigue. The methodology is based on experimental definition of fatigue parameters, a definition of the numerical model, numerical calculation of strength according to standards and estimation of fatigue strength by using experimental and numerical results. The developed methodology based on the application of numerical, theoretical, and experimental techniques of fatigue mechanics has proven to be a powerful tool for the prediction of the lifetime of structures exposed to dynamic loads.

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References

ASTM: E486-90 (2004). Standard Practice for Presentation of Constant Amplitude Fatigue Test Results for Metallic Materials.

ASTM: E606-92 (1998). Standard Practice for Strain-Controlled Fatigue Testing.

ASTM: E739-91 (2004). Standard Practice for Statistical Analysis of Linear or Linearized Stress-Life (S-N) and Strain-Life (e-N) Fatigue Data.

International Standard UIC Code 517 (2007). Wagons - Suspension gear – Standardisation.

Milovanović V, Živković M, Jovičić G, Živković J, Kozak D (2016). The Influence of Wagon Structure Part Shape Optimization on Ultimate Fatigue Strength, *Transactions of Famena*, 39-4, 23-35.

Pastor M L, Balandraud X, Robert J L, Grédiac M (2009). Lifetime prediction of aluminium structures reinforced with composite patches, *Int. Journal of Fatigue* 31, 850–858.

Stephens R, Fatemi A, Stephens R, Fuchs H (2001). *Metal Fatigue in Engineering*, New York: John Wiley & Sons Inc.

Woo C S, Kim W D (2008). Fatigue lifetime prediction methodology of rubber components, *WIT Transactions on The Built Environment*, 97, 285-293