CUMULATIVE FATIGUE DAMAGE

Conference

Seville, May 27-29 , 2003

Extended Abstracts and Papers

☐ Tuesday, 27th May 2003

- ▷ 8.30 - 9.30 h. Registration
- ▷ 9.30 - 10.30 h. Inauguration and key-note lecture
  - ○ **What is fatigue damage?**
    Professor Keith J. Miller[1] and Professor Yukitaka Murakami[2]
    [1]*Sheffield University* [2]*Kyushu University*
- ▷ 10.30 - 11.00 h. Coffee
- ▷ 11.00 - 12.30 h. 1st Session
  - ○ **Prediction of short crack growth damage accumulation in metal**
    Dorota Kocańda
    Military University of Technology, Faculty of Mechanical Engineering, Str. Kaliskiego 2, 00-908 Warszawa, Poland
  - ○ **The influence of grain size variation on metal fatigue.**
    Jenny Andersson
    Mathematical Statistics, Chalmers University of Technology, 412 96 Gôteborg, Sweden
  - ○ **Simulation of microcrack growth for different load sequences and comparison with experimental results**
    A. Ahmadi[1] & H. Zenner[1]
    [1]*Institute for Plant Engineering and Fatigue Analysis, University of Technology, Clausthal-Zellerfeld, Germany.*
- ▷ 12.30 - 14.00 h. Lunch
- ▷ 14.00 - 16.00 h. 2nd Session
  - ○ **Overloads: The effect of stress state, the near threshold behavior of long cracks and extrinsically short cracks, the difference between ductile and brittle materials**
    R. Pippan[1,2], C. Bichler[1,3], B. Tabernig[1,4], H. Weinhandl[1]
    [1]*Erich Schmid Institut für Materialwissenschaft der Österreichischen Akademie der Wissenschaften* [2]*Christian Doppler Laboratorium für lokale Analyse von Verformung und Bruch* [3]*now: AMG-Ranshofen* [4]*now: Plansee AG, Reutte*
  - ○ **An Analysis of Multiple Two-Step Fatigue Loading**
    A. J. McEvily*, S. Ishihara** and M. Endo***
    **Metallurgy Dept., U. of Connecticut, USA **Dept. of Mech. Engng., Toyama University, Toyama, Japan ***Dept. of Mech. Engng., Fukuoka University, Fukuoka, Japan*
  - ○ **Fatigue crack growth after alterations of the magnitude and direction of the loading**
    H.A. Richard, M.Sander
    Institute of Applied Mechanics University of Paderborn D - 33098 Paderborn, Germany

- **Environmental Aspects of Damage Accumulation**

  R Akid[1], I G Dmytrakh[2] & J Gonzalez-Sanchez[3]

  [1] *Centre for Corrosion Technology, Materials Research Institute, Sheffield Hallam University, Howard Street, Sheffield S1 1WB, UK* [2] *Karpenko Physico-Mechanical Institute, National Academy of Sciences of Ukraine, 5 Naukova Street, 79601, Lviv, UKRAINE* [3] *Departamento de Materiales y Corrosión, Universidad Autónoma de Campeche, Campeche, MEXICO*

▷ 16.00 - 16.30 h. Coffee

▷ 16.30 - 18.30 h. 3rd Session

- **A new model for probabilistic cumulative damage. Application to fatigue life prediction**

  J. A. Bea and M. Doblaré

  Group of Structures and Material Modeling (GEMM) Aragón Institute for Engineering Research (I3A).University of Zaragoza. María de Luna, 3 - 50018 Zaragoza (Spain)

- **Fatigue Life Assessment - Expectations and Capabilities**

  K.-G. Eulitz, K. L. Kotte

  Institute of solid-state mechanics, Technische Universitaet Dresden, Germany

- **Spectral Methods for Lifetime Prediction under Wide-Band Stationary Random Processes**

  D. Benasciutti, R. Tovo

  Department of Engineering, University of Ferrara, via Saragat, 1 - 44100 Ferrara, Italy

- **Numerical and Experimental Analysis of the Fatigue Crack Growth under Random Loading**

  J. Zapatero[1], B. Moreno[1] and J. Domínguez[2]

  [1] *Department of Civil and Materials Engineering, University of Malaga.* [2] *Department of Mechanical Engineering, University of Seville*

▷ Evening. Welcoming Reception and Cocktail. Real Alcazar.

- Wednesday, 28th May 2003
  - 9.00 - 10.00 h. Key-note lecture
    - **Fatigue Damage and Crack Growth under Variable Amplitude Loading and Counting Method of Stress-Strain Ranges**
      Professor Masahiro Jono
      Osaka University
  - 10.00 - 10.30 h. Coffee
  - 10.30 - 12.30 h. 1st Session
    - **Fatigue and damage tolerance behaviour of corroded 2024 T351 aircraft aluminum alloy**
      Sp.G. Pantelakis[1], Al.Th. Kermanidis[1] and P.V. Petroyiannis[1]
      [1]*Laboratory of Technology & Strength of Materials, Department of Mechanical & Aeronautical Engineering, University of Patras, Panepistimioupolis Rio, 265 00 Patras, Greece*
    - **Probabilistic Damage Model for Acrylic Cements. Application to the Life Prediction of Cemented Hip Implants**
      J. Grasa, M. A. Pérez, R. Ferrer, J. A. Bea, J. M. García, M. Doblaré
      Group of Structures and Material Modeling (GEMM) Aragón Institute for Engineering Research (I3A).University of Zaragoza. María de Luna, 3 - 50018 Zaragoza (Spain)
    - **Kinetic Analysis from Traces on Fracture Surface in two Cases of Fatigue Failures in Power Producing Industry**
      Sajdl P.[1], Varga L.[2]
      [1]*Power Engineering Dept., Institute of Chemical Technology, Prague Technická 5, Praha 6, Czech Republic* [2]*Vakutex s.r.o., Jezerní 1349/1, 430 03 Chomutov, Czech Republic*
    - **Cumulative Damage in an Industrial Conveyor-Belt Roller**
      K.J. Miller[1] and Y. Murakami[2]
      [1]*Department of Mechanical Engineering, University of Sheffield, Mapping Street, Sheffield, S1 3JD, UK* [2]*Department of Mechanical Engineering Science, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka, 812-8581, Japan*
  - 12.30 - 14.00 h. Lunch
  - 14.00 - 16.00 h. 2nd Session
    - **Finite element analysis of fatigue crack growth under variable amplitude loading**
      M. Sander, H.A. Richard
      Institute of Applied Mechanics University of Paderborn D - 33098 Paderborn, Germany
    - **Fatigue crack closure of a corner crack: Experimental and Finite element**
      Sarinova Simandjuntak, Hassan Alizadeh, Dr. M.J. Pavier, Prof. D.J. Smith
      Department of Mechanical Engineering, University of Bristol, Bristol BS8 1TR, UK

- **Finite element analysis of the effects of overload and underload on fatigue crack closure**
  Hassan Alizadeh, Sarinova Simandjuntak, Martyn Pavier and David Smith
  Department of Mechanical Engineering, University of Bristol, Bristol BS8 1TR, UK
- **Shape- and Topology Optimization Regarding Fatigue Analysis**
  GRUEN Florian*, EICHLSEDER Wilfried*, PUCHNER Klaus**
  **University of Leoben Franz-Josef-Strasse 18, A-8700 Leoben, Austria **Magna Steyr, Engineering Center Steyr GmbH & Co KG Steyrer Strasse 32, A-4300 St. Valentin, Austria*

▷ 16.00 - 16.30 h. Coffee

▷ 16.30 - 18.30 h. 3rd Session

- **Lifetime Prediction under Variable Amplitude Loading with the Application of Artificial Neural Networks**
  Marquardt, C.
  Institute for Plant Engineering and Fatigue Analysis, Leibniz Strasse 32, 38678 Clausthal-Zellerfeld, Germany
- **Cumulative Fatigue Damage Characterization of AISI 304L Steel Based on the Energy Dissipation**
  B. Atzori, G. Meneghetti
  Department of Mechanical Engineering, University of Padova, Via Venezia, 1 - 35131 Padova, Italy
- **The mean stress influence on fatigue strength under multiaxial out-of-phase loadings**
  L. Susmel[1], R. Tovo[1] and P. Lazzarin[2]
  [1]*Department of Engineering - University of Ferrara Via Saragat, 1 - 44100 Ferrara (Italy)* [2]*Department of Management and Engineering - University of Padova Stradella S.Nicola 3 - 36100 Vicenza (Italy)*
- **A Constitutive Model for Elastoplastic Deformation under Variable Amplitude Multiaxial Cyclic Loading**
  A. Navarro, J.M. Giráldez, C. Vallellano
  Departamento de Ingeniería Mecánica y de los Materiales, Escuela Superior de Ingenieros, Universidad de Sevilla, Camino de los Descubrimientos s/n, 41092 Sevilla, Spain

▷ Evening. Conference Dinner. Parador Nacional de Carmona.

☐ Thursday, 29th May 2003

- ▷ 9.00 - 10.00 h. Key-note lecture
  - **Experimental Results and Predictions on Fatigue Crack Growth in Structural Steel under Variable Amplitude Loading**
    Professor Malgorzata Skorupa and Professor Andrzej Skorupa
    University of Mining & Metallurgy, Krakow, Poland
- ▷ 10.00 - 10.30 h. Coffee
- ▷ 10.30 - 12.30 h. 1st Session
  - **Fatigue lifetime assessment procedures of rolling stock bogie frames**
    Byeongchoon Goo
    National Research Lab., Korea Railroad Research Institute, Woulam-Dong 385, Uiwang-City, Gyeonggi-Do, 437-825, Korea
  - **Structural Durability of Cast Aluminium Gearbox Housings of Underground Railway Vehicles under Variable Amplitude Loading**
    C.M. Sonsino
    Fraunhofer-Institute for Structural Durability (LBF), Darmstadt/ Germany
  - **Experimental and Numerical Evaluation of Cumulative Fatigue Damage of Welded Structure**
    Dr. M. Arsic[1], Prof. Dr. S. Sedmak[2], V. Aleksic[1], Mr.Sci
    [1]GOSA Institute, Milana Rakica 35, Beograd, Serbia [2]Society for structural integrity and life, Milana Rakica 35, Beograd, Serbia
  - **Fatigue Life Prediction of Welded Joints Subjected to Variable Amplitude Loading**
    Z. Perovic
    Department of Mechanical Engineering, University of Montenegro, Cetinjski put bb, 81000 Podgorica, Montenegro
- ▷ 12.30 - 14.00 h. Lunch
- ▷ 14.00 - 16.00 h. 2nd Session
  - **Fatigue Life Prediction Based on Variable Amplitude Tests - Methodology**
    Pär Johannesson*, Thomas Svensson* & Jacques de Maré†*
    **Fraunhofer-Chalmers Centre, Chalmers Science Park, 412 88 Göteborg, Sweden*
    †Mathematical Statistics, Chalmers University of Technology, 412 96 Göteborg, Sweden
  - **Fatigue life prediction based on variable amplitude tests - specific applications**
    Thomas Svensson*, Pär Johannesson*, Jacques de Maré*†
    **Fraunhofer Chalmers Research Centre for Industrial Mathematics, Chalmers Science Park, SE-412 88, Gôteborg, Sweden. †Mathematical Statistics, Chalmers University of Technology, SE-412 96 Goteborg, Sweden*

- **Generation and Use of Standardised Load Spectra and Load-Time Histories**
  P. Heuler[1)] and H. Klätschke[2)]
  [1)] *AUDI AG, Ingolstadt, Germany* [2)] *Fraunhofer-Institut für Betriebsfestigkeit (LBF), Darmstadt, Germany*
- **Fatigue life under variable-amplitude tension-compression according to the cycle counting spectral methods**
  Damian KARDAS, Tadeusz ŁAGODA, Ewald MACHA, Adam NIESŁONY
  Technical University of Opole, ul. Mikołajczyka 5, 45-271 Opole, Poland

▷ 16.00 - 16.30 h. Coffee

▷ 16.30 - 18.30 h. 3rd Session

- **Influence of Size and Type of Loading on S/N-Curve**
  TOPLACK Georg*, EICHLSEDER Wilfried**, GÓDOR István**, LEITNER Heinz***
  *) *Jenbacher AG, A-6200 Jenbach, Austria* **) *University of Leoben, A-8700 Leoben, Austria* ***) *Christian-Doppler-Laboratory for Fatigue Analysis, A-8700 Leoben, Austria*
- **Cumulative Damage under Combined Conditions of Ultrahigh and Ordinary Life Fatigue: Mechanisms and Morphology of Fatigue Fracture**
  D. Angelova*, T. J. Marrow**, St. Vodenicharov***, A. Davidkoff*
  **University of Chemical Technology and Metallurgy, Bulgaria **UMIST and Manchester University, U.K. ***Bulgarian Academy of Sciences, Bulgaria*
- **A Fatigue Test of Materials with the Strain Energy Density Amplitude Control**
  Włodzimierz BEDKOWSKI, Ewald MACHA, Jacek SŁOWIK
  Technical University of Opole, ul. Mikołajczyka 5, 45-271 Opole, Poland
- **Influence of dendrite arm spacing and porosity on the Fatigue Life of Cast Aluminium Components**
  MINICHMAYR Robert*, EICHLSEDER Wilfried**
  * *Christian Doppler Laboratory for Fatigue Analysis, Franz-Josef-Strasse 18, A-8700 Leoben, Austria* ** *University of LeobenFranz-Josef-Strasse 18, A-8700 Leoben, Austria*

- Extended abstract -

EXPERIMENTAL AND NUMERICAL EVALUATION OF CUMULATIVE FATIGUE DAMAGE OF WELDED STRUCTURE

Dr. M. Arsic[1], Prof. Dr. S. Sedmak[2], V. Aleksic[1], Mr. Sci

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1. Introduction

Frequent crack occurrence in welded components after operation in different condition of rotor excavator bearing structures is observed during service. Program of the analysis of these cracks included the identification of critical regions, measuring strains in these regions by strain gauges in different conditions, determination of stress spectrum based on performed measurements, production of model corresponding to selected welded joint from real structure and model testing by variable load of constant amplitude and by defined stress spectrum. Obtained experimental results are compared to numerical solutions, applying linear fatigue damage accumulation hypothesis by Palmgren-Miner /1, 2/, and by modified linear hypothesis, trying to correct its system errors, proposed by Corten-Dolan /3/, Serensen-Kogaev /4/ and Haibach /5/.

2. Determination of stress spectrum acting on real structure

Service life of small sized components can be assessed by corresponding fatigue experiments, but this approach in many cases can not be applied for large welded structures, e.g. rotor excavator.

In order to achieve proper construction, designer has to define critical regions of the structure and to limit maximum stress bellow allowable stress, based on experience with similar structures. In considered rotor excavator, service cracks occurred in the regions of welded joints (Fig. 1).

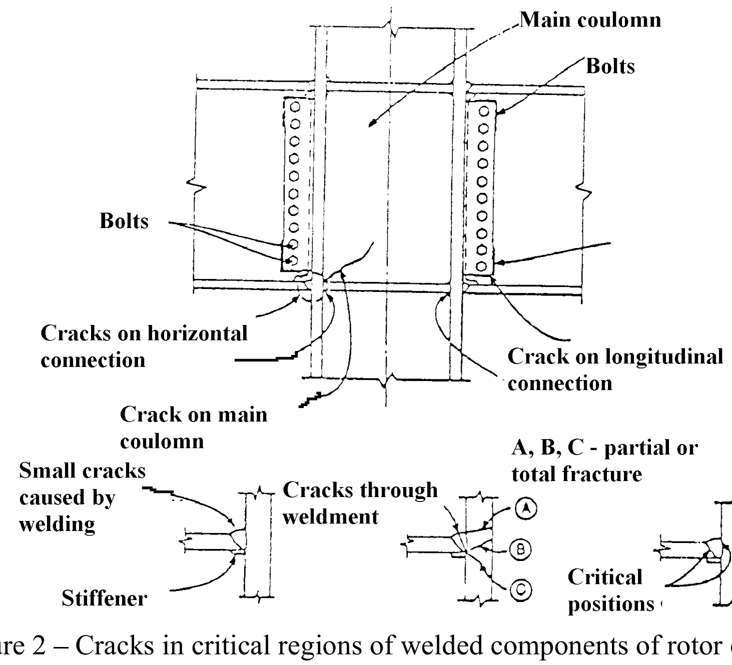

Figure 2 – Cracks in critical regions of welded components of rotor excavator

During operation rotor excavator is exposed to stresses of different origin. The bearing structure can be stressed during manufacturing and assembling of components, in the digging process and through low frequency self-vibrations, caused by movement of the excavator. Time dependent complex stress of the structure and its elements are presented as divided by stress origin (Fig. 2).

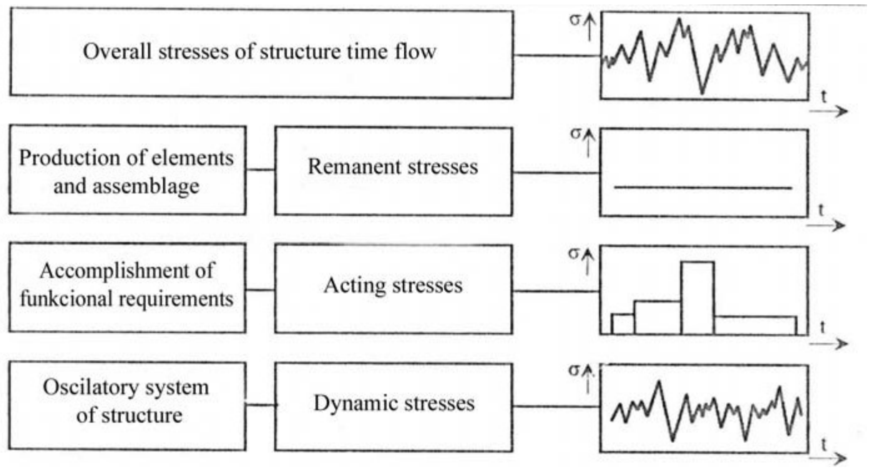

Figure 2 - Presentation of total stress as divided according to stress origin

Experimental testing of highly stressed welded components by variable loading in rotor excavator bearing structure is required for the analysis of the effect of non-stationary loading regime and low frequency self-vibrations on material fatigue behaviour. This can not be performed on real structure. Stress spectrum, caused by variable loading in different excavator operating regimes and required for evaluation of component strength, can be determined based on strains, measured by strain gauges positioned in critical regions, e.g. in welded arrow frame structure.

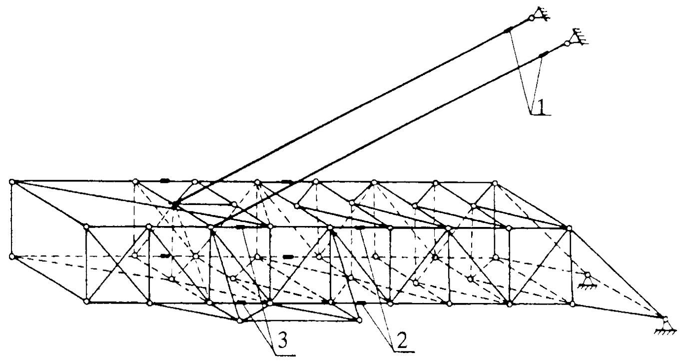

Figure 3 – Critical positions, marked by solid bold lines (2, 3), in welded arrow frame structure. Small circles correspond to crossings in Fig. 1. Tension bars are indicated by 1.

Following strain measuring have been performed /6/:

- in excavator unloading operation,
- in operation of non-charged excavator (transportation,
- in average operating condition,
- in excavator full cut condition,
- in extreme operating condition, with carefully selected loading to avoid the fracture.

Statistical data for percentage of different loading conditions are given in Table 1.

Table 1. Statistical data for time percentage of different loading conditions

Loading	Transport	Average	Full cut
Loading percentage, %	4	60	36

Using statistical method, acting stress spectra are found for different operating regimes of rotor excavator, for derived stress range σ_r and mean stress value σ_m, as described in ref. /6, 7/. By discreditation of experimentally obtained stress variations in time (Fig.4), using rain-flow method, the characteristics of random loading process are derived.

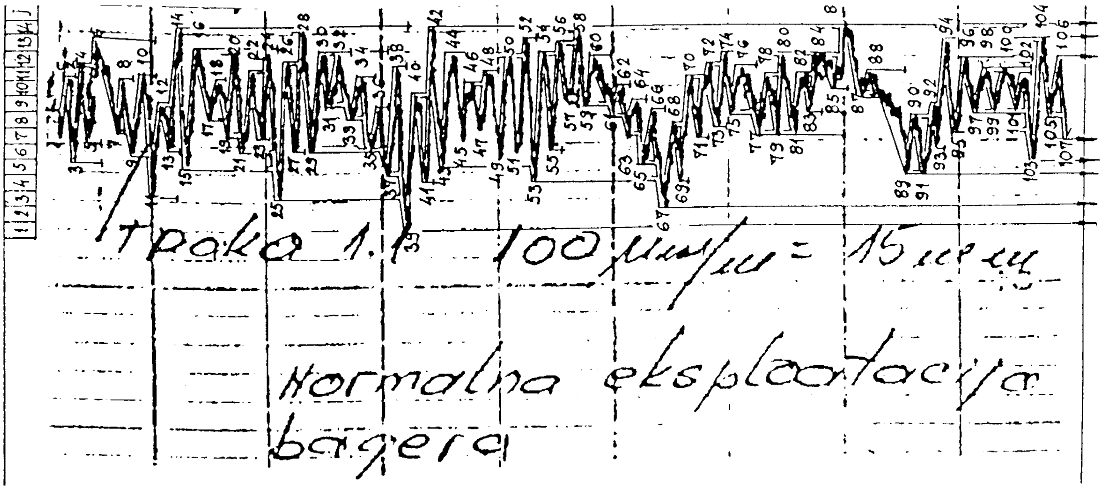

Figure 4 – Process of discreditation of experimentally obtained stress variations in normal service of rotor excavator

Weibull distribution is most convenient for description of acting stress range, as it is confirmed by graphical and analytical nethods of probability theory and mathematical statistics. Based on operating regime percentage data (Table 1), the general form for stress function could be derived:

$$H(\sigma_r) = 1 - F(\sigma_r) = 0.04 \cdot exp\left[-\left(\frac{\sigma_r}{\eta_1}\right)^{\beta_1}\right] + 0.60 \cdot exp\left[-\left(\frac{\sigma_r}{\eta_2}\right)^{\beta_2}\right] + 0.36 \cdot exp\left[-\left(\frac{\sigma_r}{\eta_3}\right)^{\beta_3}\right] + ... \quad 1.$$

Here, η coefficients are characteristics of stress value for probability level 0.62 and the slopes of corresponding lines are characterized by β. The total spectrum of stress range is obtained by introducing also the pik stress, defined by the extrapolation of pik value distribution. These loadings, which can arrest the excavator in operation, represent 0.05 to 10% of total operating time, and can reach the value three times higher than full cut loading /6/.

3. Experimental testing

In order to get the data for fatigue properties (S – N curve) of welded joint of steel Č.0563 (St52.3 – DIN, S355 - ISO), testing had been performed by constant loading amplitude and than by variable loading amplitude, e.g. by stress spectrum obtained by experimental measurement of strains. Design of cross welded joint specimen (Fig. 5) had been modeled to simulate one typical welded joint of bearing structure components of rotor excavator arrow.

Fatigue experimental testing of designed specimen had been performed with constant amplitude loading on high-frequency resonant pulsator Amsler, capacity 100 kN. Obtained S – N curve is presented in double logarithmic diagram in Fig. 6, with exponent m = 6.7 ($S^{6.7}N$ = const), and in Fig. 7, designed as F.S.

Applying defined loading spectrum, fatigue experimental testing of designed specimen had been performed on servohydraulic closed loop MTS device. Corresponding S – N curve is presented in Fig. 7, designed as A.S.

4. Damage accumulation hypothesis and the assessment of fatigue life by calculation

According to frequently used linear fatigue damage accumulation hypothesis of Palmgren-Miner total damage accumulation in general form reads:

$$D = \sum_{i=1} \left(\frac{n}{N} \right)_i \qquad 2.$$

where n presents actual cycle number and N is cycle number required for failure at determined stress level i, comprising that fracture occurred for value D = 1. For metallic materials in general, value of D is ranged between 0.1 and 1, and for large size welded structures is about 0.5 /8/.

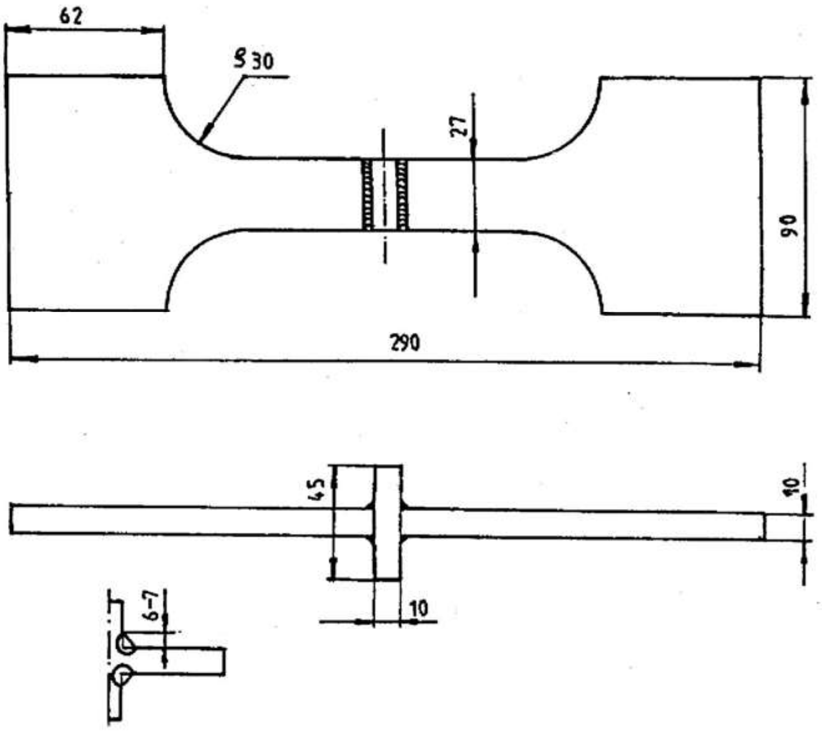

Figure 5 - Specimen for fatigue testing, model of cross welded joint of rotor excavator arrow

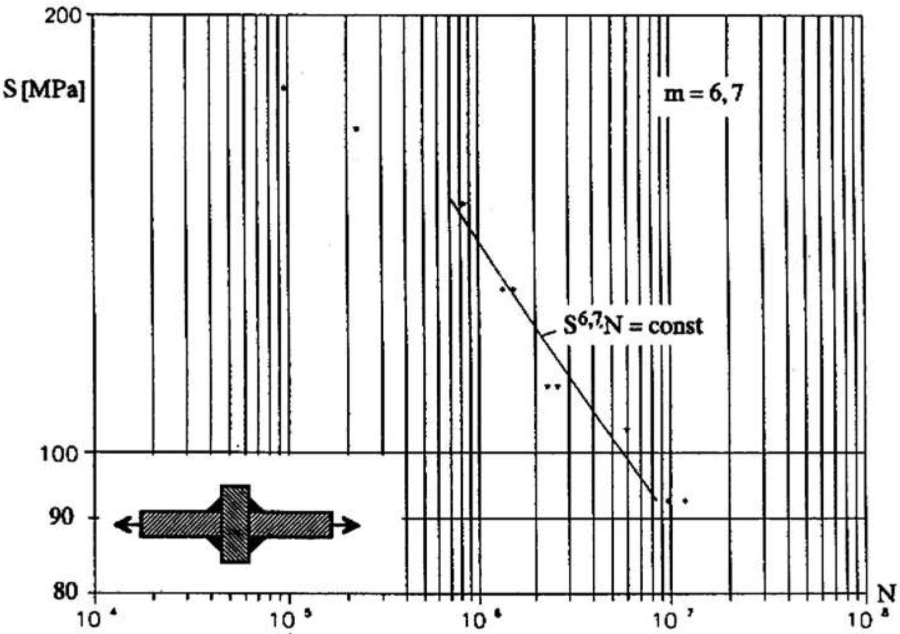

Figure 6 - Experimental S – N curve for cross welded joint specimen, obtained with constant amplitude loading

Based on experimental test results and derived unit stress spectrum, characteristic values for fatigue life numerical evaluation, listed in Table 2, are calculated applying different linear hypothesis of damage accumulation.

The results of the calculation for four cumulative damage hypothesis are compared in Fig. 7 to experimentally obtained values for constant amplitude loading (F.S.) and for variable loading of loading spectrum (A.S.).

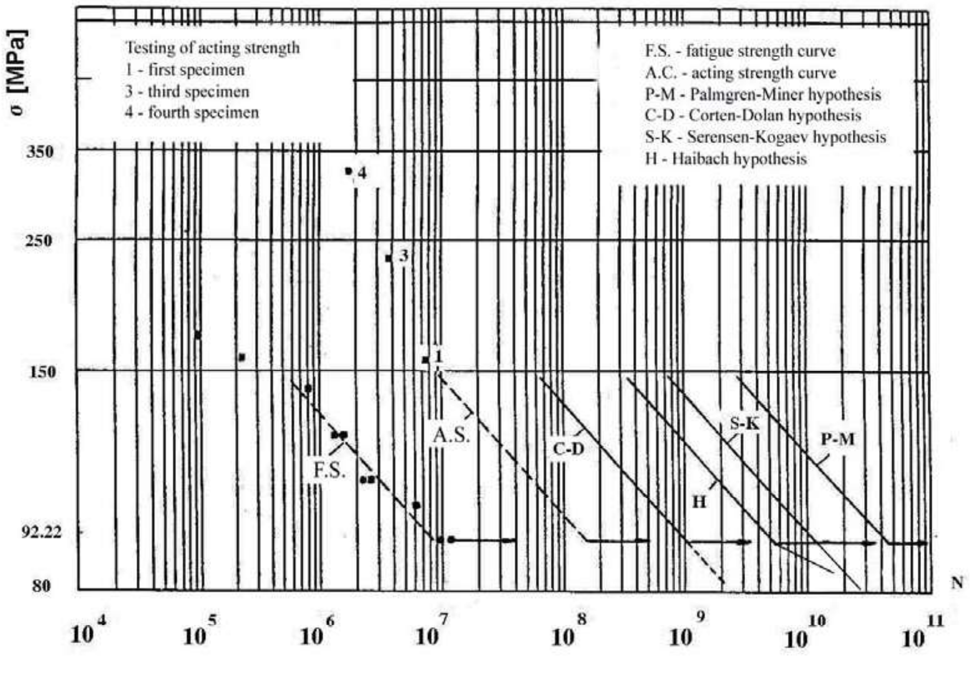

Figure 7 - Comparison of S – N curves, obtained experimentally with constant (F.S.) and variable amplitude loading spectrum (stress spectrum) (A.S.) and calculated by linear accumulation hypothesis (Corten-Dolan – C-D, Haibach – H, Serensen-Kogaev – S-K and Palmgren-Miner – P-M)

Table 2. Characteristic values, required for fatigue life calculation

	i	1	2	3	4	5	6	7	8
1	Δn_{bi}	1	19	58	504	3824	21112	54326	85462
2	$\Delta n_{bi}/n_b$	6x10^{-6}	1.15x10^{-4}	3.5x10^{-4}	3.05x10^{-4}	0.023	0.128	0.329	0.517
3	σ_r, MPa	141.38	94.26	90.22	80.78	68.66	53.9	40.4	26.92
4	σ_{ri}/σ_{r1}	1	0.667	0.638	0.5714	0.486	0.381	0.286	0.191
5	$(\sigma_{ri}/\sigma_{r1})^{6.7}$	1	0.066	0.049	0.024	0.0079	0.0016	0.00023	0.000015
6	$(\Delta n_{bi}/n_b)(\sigma_{ri}/\sigma_{r1})$	6x10^{-6}	7.67x10^{-5}	2.23x10^{-4}	1.74x10^{-3}	0.0112	0.0488	0.094	0.099
7	$(\Delta n_{bi}/n_b)(\sigma_{ri}/\sigma_{r1})^{6.7}$	6x10^{-6}	7.63x10^{-6}	1.72x10^{-5}	7.17x10^{-5}	1.82x10^{-4}	2x10^{-4}	7.46x10^{-5}	7.71x10^{-6}
8	$(\sigma_{ri}/\sigma_{r1})^{12.4}$	1	6.59x10^{-3}	3.8x10^{-3}	9.68x10^{-4}	1.29x10^{-4}	6.41x10^{-6}	1.8x10^{-7}	1.17x10^{-9}
9	$(\Delta n_{bi}/n_b)(\sigma_{ri}/\sigma_{r1})^{12.4}$	6x10^{-6}	7.58x10^{-7}	1.33x10^{-6}	2.95x10^{-6}	0.03x10^{-4}	0.82x10^{-6}	0.59x10^{-7}	0.61x10^{-9}

Explanation of used values:
Δn_{bi} – number of stress changes at level i in unit spectrum n_b = 165306 cycles
σ_r, MPa – stress range
σ_{r1}, MPa – stress range value at first level in unit spectrum (the highest stress value in unit spectrum)
σ_{ri}, MPa - stress range value at level i in unit spectrum
m = 6.7 – exponent of base S – N curve
$2m$ – 1 = 12.4 – exponent of second segment in S – N curve according to Haibach hypothesis

4.1. Palmgren-Miner hypothesis

Basic approach for fatigue life, given by Eq. 1, had been proposed by Palmgren /1/. It is extended by Miner /2/, with proposal that only amplitude stresses σ_{ai} higher than fatigue limit σ_D contributes to damage accumulation. From Eq. 2 it follows

$$N_i \sigma_{ai}^m = N_D \sigma_D^m \qquad 3.$$

with subscript D indicating fatigue limit. For stress spectrum, Miner defined relation:

$$N_{R_{P-M}} = \frac{N_1}{\sum_{i=1}^{j} \frac{\Delta n_{bi}}{n_b} \cdot \left(\frac{\sigma_{ri}}{\sigma_{r1}}\right)^m} = \frac{586650}{13.63 \cdot 10^{-6}} = 4.304 \cdot 10^{10} \qquad 4.$$

in which $N_D = 10^7$, σ_D = 9.22 MPa, σ_{r1} = 141,38 MPa, m = 6.7, with j = 2 - stress levels in spectrum, higher than fatigue strength value.

4.2. Corten-Dolan hypothesis

This hypothesis includes all amplitudes of stress as responsible for cumulative damage. Accordingly, fatigue life is:

$$N_{R_{C-D}} = \frac{N_1}{\sum_{i=1}^{k} \frac{\Delta n_{bi}}{n_b} \cdot \left(\frac{\sigma_{ri}}{\sigma_{r1}}\right)^m} = \frac{586650}{566.903 \cdot 10^{-6}} = 1.0348 \cdot 10^9 \qquad 5.$$

with k = 8 - all stress levels in spectrum.

4.3. Serensen-Kogaev hypothesis

This hypothesis involves also the stresses, lower than fatigue limit, for fatigue life calculation. They defined stress interaction function a_p (in range 0.2 to 1) in the form:

$$a_p = \frac{\frac{\sigma_1}{\sigma_D} \cdot \sum_{i=1}^{k} \frac{\Delta n_{bi}}{n_b} \cdot \frac{\sigma_{ri}}{\sigma_{r1}} - 0.5}{\frac{\sigma_1}{\sigma_D} - 0.5} = \frac{\frac{141.38}{92.59} \cdot 0.5457 - 0.5}{\frac{141.38}{92.59} - 0.5} = 0.325 \qquad 6.$$

which takes into account, based on experimental evidence, all stresses higher than $0.5\sigma_D$. In considered case, fatigue life is calculated as:

$$N_{R_{S-K}} = \frac{a_p \cdot N_1}{\sum_{i=1}^{j} \frac{\Delta n_{bi}}{n_b} \cdot \left(\frac{\sigma_{ri}}{\sigma_{r1}}\right)^8} = \frac{0.325 \cdot 586650}{13.63 \cdot 10^{-6}} = 1.397 \cdot 10^{10} \qquad 7.$$

4.4. Haibach hypothesis

Considering fatigue behaviour of welded structures, Haibach concluded that all amplitudes in stress spectrum contribute to damage accumulation, but the effect of stresses higher than fatigue limit is much more expressed than that of lower values. In the range of fatigue limit he introduced fictive fatigue curve, starting in point (N_D, σ_D) with the slope $2m - 1$ (12.4 for given data). So:

$$N_{R_H} = \frac{N_1}{\sum_{i=1}^{j} \frac{\Delta n_{bi}}{n_b} \cdot \left(\frac{\sigma_{ri}}{\sigma_{r1}}\right)^m + \left(\frac{\sigma_1}{\sigma_D}\right)^{m-1} \cdot \sum_{i=j+1}^{k} \frac{\Delta n_{bi}}{n_b} \cdot \left(\frac{\sigma_{ri}}{\sigma_{r1}}\right)^{2m-1}} = \qquad 8.$$

$$\frac{586650}{13.63 \cdot 10^{-6} + \left(\frac{141.38}{92.59}\right)^{5.7} \cdot 8.129 \cdot 10^{-6}} = 5.62 \cdot 10^9$$

5. Discussion and conclusion

The comparison of fatigue testing results, obtained with constant loading amplitude and stress spectrum, shows that the effect of constant amplitude is more expressed (Fig. 7), indicating that the structure in real operating condition with different amplitude can exhibit longer fatigue life than expected based on laboratory test by constant amplitude. This can also be applied to fatigue strength of bearing structure components of rotor excavator. The comparison of results for fatigue limit, obtained by experiment with stress spectrum and by the application of this spectrum for the calculation using four hypothesis revealed that hypothesis significantly overestimate the number N_D for fatigue limit. The first introduced hypothesis by Palmgren and Miner produces the longest life, far from the value obtained in experiments with stress spectrum. Similar property can be attributed to Serensen-Kogaev hypothesis. The hypothesis of Corten-Dolan can be evaluated as the closest to real behaviour, but also Haibach hypothesis can be applied, being proposed for welded joints.

Anyhow, in consideration of applicability of proposed hypothesis, their relation to experimental results has to be taken into account. The same is valid for the other structures with similar loading history or to the same structure, exhibiting different loading history.

References

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