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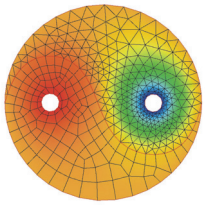

UNCERTAINTY OF LIFETIME EVALUATION FOR CAFE CREEP DAMAGE MODEL

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Abstract

In the paper the influence of material microstructure randomness upon statistically observed scatter of experimental results on macroscopic level is searched through. It is well known that a lot of random factors influence the lifetime of engineering structures working under elevated temperatures, like variations of loading and temperature. Although they can be controlled in laboratory conditions the scatter of experimental results of creep tests is still very large. Remaining variability is mainly due to randomness of material structure. Not only lifetime of structure, set here as the time to first macroscopic defect, but also other parameters like strain to failure or steady-state strain rate are of random characters. Macroscopically the scatter of creep test results can be modelled by some probabilistic distribution of material parameters used in macroscopic equations. But this approach cannot explain the reasons of this scatter. To reflect the importance of material structure the multiscale model has been built where the influence of polycrystalline grains pattern on damage development process is modelled by cellular automata simulation described in previous author's papers. Material structure is homogenous as all grain properties, including mean grain diameter over Representative Volume Element remain constant. Macroscopic results obtained by the model are statistically analysed. Proposed model predicts the scatter of time to failure in range of scatter of experimental results for intergranular failure mode.

Key words: randomness of creep failure data, creep fracture, damage mechanics, Cellular Automata, CAFE

1. INTRODUCTION

One of the most important features in engineering design of a structure working at elevated temperatures is prediction of its lifetime. Large number of models have been built for description of creep damage process, but the main problem in their verification is a scatter of experimental results. For example data of time to creep failure for 1/2Cr 1/2Mo 1/4V steel analysed by Evans (1995) shows the scatter up to 7 orders of magnitude in the same temperature and stress condition. The main sources of so large variability were often attributed to the differences in chemical composition or heat treatment which results in different material structure (Harlow et al., 2000). But even for the same structure the scatter is significant. Experiment of Farris et al. (1990) shows that for six specimens cut from one copper bicrystal the coefficient of variations of time to failure is about 60%. The authors tried to explain this scatter by the variability of external conditions like loading or temperature. The most important of them appeared the loading eccentricity. But the coefficient of variations due to it was estimated up to 10%, so the scatter observed in experiment has to be explained by other factors. Assuming that the initial material structure is the same and the external conditions do not influence the scatter, the only reason for it may be randomness of creep deformation and damage development processes.

There are very few works examining the scatter of creep test results due to differences in internal

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structure (except the influence of grain size). Roy et al. (2010) performed a series of four tests in identical test condition on SS304 LN steel, two of them leading to fracture of specimen. The difference in time to fracture was about 25%. The authors examined the fractured surfaces and concluded that the difference is in the number of un-dissolved carbides leading to different mechanisms of damage. One was pure intergranular as the damage was caused by wedge-like grain boundary cavities, the second one was mixed-mode, as fracture surface was dimpled and grain boundary cavities were elliptical.

It is common assumption that the reason of differences is the topology of grain structure. The most works concerning this problem are numerical analysis as it is very difficult to examine the influence of topology experimentally. Van der Giessen et al. (1997) compared computed time to failure for numerical models of regular array of hexagonal grains and similar array but with random offset of some parameters (triple points' or nuclei points' locus, grain sizes). The models in above paper simulate micromechanisms of creep deformation and nucleation and growth of cavities. The results of simulation show that irregular grain structure exhibits time to failure up to 50% less than regular one.

The creep failure cannot be considered separately from deformation. The process of damage development is strictly connected with mechanism of deformation. It is well documented on macroscopic level of observation (e.g. Monkman-Grant relation, equation 1, Monkman & Grant 1956) and on microscopic level (e.g. constrained diffusive cavitation mechanism, Dyson 1976). So the scatter of time to failure has to be preceded by scatter of results measured during primary and secondary creep. The parameter of primary interest in these periods is minimum strain rate. The scatter of it is also large, but less that of time to failure (for review see Harlow et al., 2000). Unfortunately works about the variability of strains during primary and secondary creep are very seldom.

The scatter of time to failure is derived from scatter of minimum strain rate and other parameters connected with material resistance to damage. It can be expressed by Monkman-Grant relation (Monkman & Grant, 1956):

$$t_f = C\dot{\varepsilon}_{min}^{-\beta}, \tag{1}$$

where t_f is time to failure, $\dot{\varepsilon}_{min}$ is minimum strain rate, C, β are material parameters. In terms of probability analysis the scatter of time to failure is often described by log normal distribution (for other distributions see Evans, 1995), as it can be considered as multiplication of many random, independent variables. Equation 1 can be viewed as an example of such multiplication.

2. MACROSCOPIC CDM DESCRIPTION

Taking into account the large variability of creep test results, the deterministic equations developed within the framework of Continuum Damage Mechanics (CDM) seems to be inadquate for description of this phenomenon. The main problem in CDM analysis is determination of material parameters, e.g. the values of n and B in the most popular Norton law:

$$\dot{\varepsilon}_{min} = B\sigma^n, \tag{2}$$

where σ is applied stress. Data for 21/4Cr 1Mo steel in temperature 566°C reported by Deplh and Yukich (1992) varies: n from 5 to 12, B from $5\text{x}10^{-15}$ to $3\text{x}10^{-27}$ MPa^{-n}/h. Applying these values (taking into account the strong correlation between them - the correlation coefficient of n and $\ln(B)$ is -0.993) gives the scatter of creep rate over two orders of magnitude. This example emphasises the problems encountered in extrapolating the results from one experiment to another. But when the joint probability density function is known for all material parameters it is possible to analyse the structure and calculate its response in probabilistic manner (cf. e.g. Deplh & Yukich, 1992).

But the CDM calculation can be very helpful in estimating the variability of time to failure originated from both external and internal sources. The example of the first is a work of Hayhurst (1974), where the influence of loading eccentricity on time to failure is examined. This deterministic analysis shows that eccentricity of order of 1.5% caused the reduction of time to failure by 60%. The size of this reduction strongly depends on the value of exponent n in Norton law of creep.

Effects of internal sources of random behaviour were analysed by Bodnar et al. (2008) for creeping plate under constant pressure. The initial state of material was modelled by random spatial distribution of nonzero damage parameter, keeping the total mean value of damage parameter constant (from 0.35% to 1.80%). The calculated reduction of time to first crack appearance was up to 80% for highly localised large initial damage. But the reduction of

the time to crack proliferation was only 15% irrespective of initial damage spatial distribution. The latter case shows the effect of stress redistribution in creep condition in which load bering cappacity of material is shifted from more damaged regions to less damaged ones. In similar way other structural parameters describing for instance dislocation density or particulate microstructure can be analysed but it requires their governing equations and additional material parameters.

In recent years multiscale modelling starts to play primary role in description of complex structures and processes. This approach enables to avoid very complicated constitutive equations. The entire problem can be divided to smaller ones according to its scale. Additionally simultaneously running models responsible for their own mechanisms allow for mixing different modelling techniques.

3. CELLULAR AUTOMATA

Cellular Automata (CA) are a tool very suitable for modelling random aspects of material behaviour (cf. Raabe, 2002). CA consist of regular lattice built of cells, space of state variables and set of rules, which govern state's transitions. Every cell is described by a value of state variable or variables. Rules changing the value of state variables are local, i.e. the state value in next time step depends on current state values of the cell itself and its neighbourhood. If this rule depends on some random variables the CA are probabilistic. In current paper CA are used for modelling of creep damage development on the level of material structure. This model is based on 2-D CA model described in previous author's papers (Nowak, 2009; Chrzanowski & Nowak 2009). Two sources of variability are considered in present paper: first is material structure, second is randomness of the process of damage development.

3.1. Modelling of material structure

The model of material structure is related to the homogeneous grain structure of polycrystalline material. The structure is modelled for Representative Volume Element (RVE), which consists at least of several grains. All cells outside of RVE have the state value equal to -1. The grains are distinguished by value of state variable. Cells belonging to the same grain have the same positive state value. If the cell lies inside grain all its neighbours have the same state value, if it belongs to grain boundary at least one of its neighbours has another, but also positive state value. The number of grain seed points is a model parameter - n_{seed}. It is not exactly the number of grains within RVE as neighbouring grains of the same state value can join together. The loci of seed points are random variable with uniform spatial distribution limited to RVE. The grains are creating using discrete Voronoi tessellation by algorithm described in paper (Chrzanowski & Nowak, 2009).

The second aspect of the initial structure is initial damage distribution. The damage is modelled by so called empty cells with state value equal to zero. The cells with state value greater than zero are called mass cells. Initial number of empty cells is determined by g_{dam0} parameter, which is defined as a ratio of empty cells to RVE size in cells. These cells are dispersed randomly over the RVE with uniform spatial distribution. The role of initial damage distribution is twofold. Firstly it represents the initial defects in real structure, secondly it simulates the initial vacancy concentration. The size of single vacancy (10^{-10}m) is very small in comparision to size of smallest noticeable defects (about 10^{-8}m). So it is questionable to model them using the same tool. But it simplifies the model and allows easy control the number of empty and mass cells in RVE.

The third parameter describing the structure is N_{init} defined as a number of cells along one side of RVE. This parameter is not connected with material structure but with resolution of automaton.

3.2. Model of damage development process

Creep damage development is considered as the process of nucleation, growth and coalescence of microvoids or microcracks (cf. e.g. Riedel, 1987). The process depends on many circumstances. The most important of them are applied stress level and temperature. The process is intergranular for low stresses (comparing to yield stress) and medium temperatures (up to 50% of melting temperature). The voids nucleate at grain boundaries (mainly transversal to the direction of tension) and grow up to coalescence with neighbouring voids forming microcracks along grain boundaries. For higher stress or temperatures process is transgranular or mixed. In transgranular failure the voids nucleate at grain boundaries or inside grains at some precipitates. They grow to large dimension forming elliptical shape that is elongated in tension direction. They coalesce with neighbouring ones by internal necking or voids sheeting mechanisms. The voids growth is controlled by diffusion of vacancies or by deforma-

tion of surrounding material. These two basic mechanisms may run separately or diffusive growth can be inhibited or enhanced by deformation (cf. e.g. Cocks & Ashby, 1982).

The CA model reflects these two basic mechanisms. Precise description of the implementation can be found in (Nowak, 2009; Chrzanowski & Nowak 2009). Simulation of diffusive movement of vacancies is made by movement of single empty cells. The cells aggregate into voids, which can nucleate on grain boundaries due to surface energy criterion. The movement is possible only if it not enlarge value of J:

$$J = w_{e-m} l_{e-m} + w_{g-g} l_{g-g}, \tag{3}$$

where $w_{e\text{-}m}$ is weight factor for empty-mass border and $l_{e\text{-}m}$ is number of neighbouring pairs empty-mass cells, and $w_{g\text{-}g}$ is weight factor for grain-grain border and $l_{g\text{-}g}$ is number of neighbouring pairs belonging to different grains. According to the values of weight factors empty cells may aggregate into elliptical ($w_{e\text{-}m}$ is positive and $w_{g\text{-}g}$ is zero) or intergranular cracks ($w_{e\text{-}m}$ is zero and $w_{g\text{-}g}$ is positive). When both values are positive the voids are forming lens-like shapes. The calculations are made locally, within neighbourhood of cells under consideration. The number of empty cells is constant in diffusion process.

Deformation algorithm is based on work of Matic and Geltmacher (2001) implemented to polycrystalline material structure (Nowak, 2007; Chrzanowski & Nowak, 2009). The dimensions of RVE are changed according to external for the CA rules during deformation, but the volume of RVE (calculated as a number of cells within RVE) remains approximately constants. According to change of RVE dimensions the structure of grains built of mass and empty cells is stretched and then projected over CA cells grid. But the stretching is not uniformly distributed over whole grid. To avoid artificial accumulation of empty cells it is disturbed by some random variable (cf. Matic & Geltmacher, 2001).

The deformation is a source of new empty cells, as it is assumed that during tension mass density decreases. Mass density is calculated in every time increment as

$$\rho = \frac{M}{V} = \frac{V - E}{V}, \tag{4}$$

where M is number of mass cells within RVE, E is number of empty cells within RVE, V is overall number of cells in RVE - volume of RVE. Mass density is controlled by new empty cells, which can occur during deformation, according to empirical equation (cf. Belloni et al., 1977):

$$\rho = \rho_0 \left(1 - H\varepsilon^{\gamma}\right), \tag{5}$$

where $\rho_0 = \frac{M_0}{V_0}$ is the initial density, ε is linear strain, H and γ are model parameters. Equation 5 is a way of coupling between diffusion and deformation processes. For small strains there are a few new empty cells so diffusive growth is inhibited by deformation, for large strains there are lots of new empty cells and the growth is enhanced by deformation.

There are three points where randomness is introduced in above outlined procedure. First, in mechanism of stretching during deformation, there is a random variable disturbing mesh before projection. This variable has a uniform distribution within a range from (-0.5, 0.5), where 1 is size of single cell. It is responsible for rapid increase of single intergranular cracks, occurring when extreme values of this variable are located at grain boundary. Second point is for diffusive motion of empty cells, the direction of motion is chosen randomly. Third one is location of new empty cells produced in deformation algorithm.

3.3. Determination of time to failure

The value of damage parameter for RVE is calculated in every time step. All clusters of connected empty cells are searched through and the one of maximum relative linear size is chosen. The value of damage parameter is calculated as the size of projection of this cluster upon RVE side related to size of RVE in that direction. When value of damage parameter reaches one, the failure of RVE is assumed. In such situation the cluster of empty cells makes a connection between opposite side of RVE.

4. MULTISCALE CAFE MODEL

Microscopic model of damage is connected with model of deformation in macroscale. As the macro model use Finite Element Method they compose together multiscale model according to CAFE (Cellular Automata Finite Element) technology (cf. Das et al., 2001). FE solver calculates solution of constitutive equation for creep deformation in form of:

$$\dot{\varepsilon} = f(\sigma, \varepsilon, \omega), \tag{6}$$

where ε denotes strain, σ is stress, ω is damage parameter. An instance of CA model is running in every Gauss point of FE mesh. The strains obtained by FE solver are used to determine the current size of RVE. Next the CA runs appropriate number of CA iterations to cover the time increment of FE. The model parameter Δt is responsible for time control of CA. It is time (in seconds) of one CA iteration. The value of damage parameter assigned by CA is used by FE in next time increment.

The deformation model used in previous works (Nowak, 2009; Chrzanowski & Nowak, 2009) assumed irrelevant influence of primary creep to final strains. But in many cases strains at end of primary period of creep constitutes significant part of strain at failure. Although the times to failure obtained by the model were correct, it was not so with strains at failure. To properly model them the whole creep curve has to be simulated. The current model utilizes the idea proposed by Chrzanowski (1972) to model three periods of creep curve by coupling hardening model of primary creep with softening model of tertiary creep (due to damage development). The constitutive equation for creep deformation after Chrzanowski (1972) is:

$$\dot{\varepsilon}_c = B_1 \varepsilon_c^{-\alpha} \left(\frac{\sigma}{1-\omega} \right)^{n_1}, \tag{7}$$

where B_1, n_1 and α are material constants; ε_c is creep strain. The steady state creep rate is obtained when effects of hardening and softening are abolishing each other.

Parameters for equation 7 can be obtained from data of primary creep as it is derived from Andrade equation for primary creep:

$$\varepsilon_c = \beta t^{1/3}, \tag{8}$$

where β is parameter depending on applied stress. The value of β in $s^{-1/3}$ is equal to creep strain after 1 s. After differentiation of equation 8 strain rate of primary creep is:

$$\dot{\varepsilon}_c = \tfrac{1}{3} \beta^3 \varepsilon_c^{-2}. \tag{9}$$

Assuming exponential relation between β and stress equation 9 can be stated:

$$\dot{\varepsilon}_c = B_1 \sigma^{n_1} \varepsilon_c^{-2}, \tag{10}$$

where $\beta = (3B_1)^{1/3} \sigma^{n_1/3}$. Comparing equations 7 and 10 it is seen that parametr alfa can bee set to $\alpha = 2$, if value of damage parameter is small enough to be neglected.

5. EXAMPLE

5.1. Estimation of deformation model parameters (FE)

There are very few results of experiments available in literature with full description of all creep periods. The precise results of creep experiment are documented by Feltham and Meakin (1959) for oxygen-free high-conductivity copper (purity 99.99%) of constant grain size (30 μm) in temperature 823 K. Their experiment was performed in constant stress condition and full data are reported for five stress levels from 28 to 52 MPa. The data for primary creep fit very well to Andrade equation 8. The values of material constants for primary creep are: B_1 = 7.57E-24 $(MPa)^{-n_1}s^{-1}$, n_1 = 9.76. For comparison the values of parameters of equation 2 estimated from data of secondary creep are: B = 2.24E-13 $(MPa)^{-n}s^{-1}$, n=5.21.

Data for copper exhibit also noticeable value of instantaneous strain ε_0 in this temperature:

$$\varepsilon = \varepsilon_0 + \varepsilon_c. \tag{11}$$

According to Wilshire and Battenbough (2007) yield stress in 823K is about 15 MPa. The dependency of instantaneous strain upon stress was estimated from strains after 1 s (Feltham & Meakin, 1959), see figure 1. Theoretical instantaneous strain (at 0 s) can be calculated subtracting value of β.

Parameters of equation 7 were estimated assuming that value of damage parameter during primary creep is close to zero. It is not so with current model of damage. To account the effect of non-zero initial damage and keeping the values of primary creep parameters, equation 7 was rearranged into:

$$\dot{\varepsilon}_c = B_1 \varepsilon_c^{-\alpha} \left(\frac{\sigma(1-\omega_0)}{1-\omega} \right)^{n_1}, \tag{12}$$

where ω_0 is additional model parameter. Its value was estimated to 0.15 by fitting curves obtained from equation 10 and it is close to mean value of damage parameter obtained with CAFE model after 1 s.

The FE model consists of four plain strain elements. Each element has four Gaussian points. So

the model consists of 16 CA instances. The model was assumed to be a 1/4 of symmetrical specimen, so on two edges symmetrical boundary condition was set. Tension was applied with constant stress value in one direction. Simulations were run on Abaqus FE system.

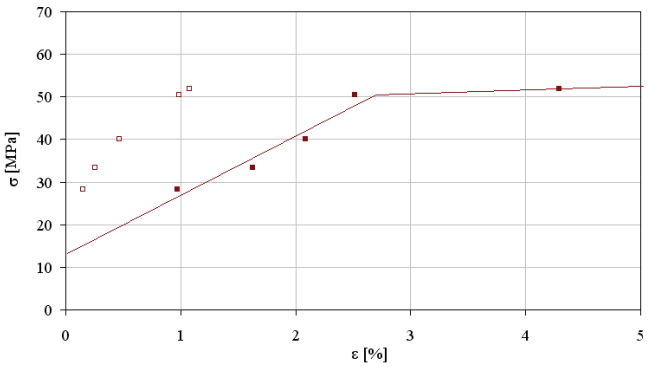

Fig. 1. *Estimation of yield function (line); experiment results at 1 s after applied stress σ (full squares), cf. Feltham and Meakin (1959); creep strains after 1 s (open squares), estimated according to equation 8.*

5.2. Estimation of damage development model parameters (CA)

The structure parameters of CA model were assumed to be: $N_{init} = 641$, $n_{seed} = 10$, $g_{dam0} = 0.005$. The mean grain diameter is about 200 cells, so for model of 30 μm grains, it gives 0.15 μm linear dimension of one CA cell. This size is the size of smallest noticeable by model void.

Table 1. *Results of CAFE simulation for random initial structures.*

nominal stress	primary strain		steady state creep rate		time to failure		strain to failure	
σ [MPa]	ε_p [%]		$\dot{\varepsilon}_s$ [s^{-1}]		t_f [s]		ε_f [%]	
	mean v.	std. dev.	mean v.	std. dev.	mean v.	std. dev.	mean v.	std. dev.
26.0	2.74	0.58	4.99E-6	1.85E-6	8.96E3	3.83E3	7.3	2.0
28.4	3.07	0.63	6.93E-6	2.32E-6	6.13E3	2.41E3	7.8	2.0
33.3	3.23	0.23	2.04E-5	3.10E-6	2.87E3	5.30E2	9.9	1.3
40.1	3.93	0.36	5.58E-5	6.51E-6	1.19E3	2.78E2	11.4	2.4
50.5	5.05	0.39	1.84E-4	2.19E-5	6.99E2	2.43E2	22.3	9.1
52.0	6.72	0.27	2.60E-4	3.66E-5	4.73E2	1.09E2	21.9	2.7

The experimental observations confirmed mainly intergranular cracking (cf. Feltham & Meakin, 1959) so values $w_{e\text{-}m} = 0$ and $w_{g\text{-}g} = 1$ were established. The parameters of equation 5: $H = 1.17$ and $\gamma = 2.3$ were obtained by regression analysis of data for copper in temperature range 673–823 K and stress range 21–34 MPa (cf. Boettner & Robertson, 1961).

The value of time increment $\Delta t = 0.3$ s was set to fit the experimental times to failure.

5.3. Results of simulations

The simulations were run for six levels of loading corresponding to following stresses in experiment of Feltham and Meakin (1959): 26.0, 28.4, 33.3, 40.1, 50.5 and 52.0 [MPa]. For every stress six initial grain configurations were examined. Table 1 presents the mean values and standard deviations of primary strain, steady state creep rate, time to failure and strain at failure. Primary strain is defined here as strain at time equal to zero obtained by extension of steady state creep line (see figure 2).

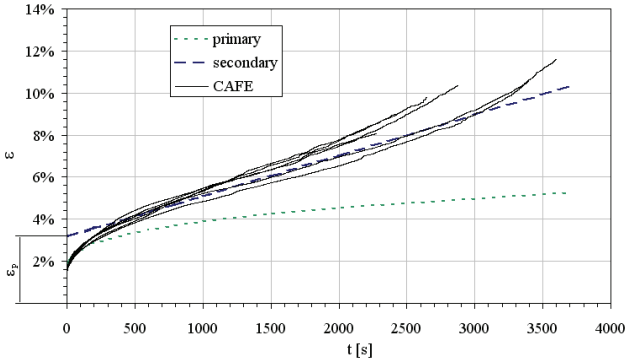

Fig. 2. *Results of CAFE simulation for 33.3MPa for six initial structures; dotted line is primary creep according equation 8; dashed line is extended line of steady state creep suited to experiment results (Feltham & Meakin, 1959).*

Shape of creep curves obtained in simulations concides with shape of experimental curves. The three periods of creep can be distinguished and appropriate parameters assigned. In comparison with experimental results it is seen that steady state creep rate is too large for high stresses and too small for law stresses (see figure 3a). It can be a result of single function for density changes (according to experiments it depends on stress) or single parameter ω_0. Determination of primary strain from simulation creep curves is ambiguous. It strongly depends upon the assumed limits of secondary creep but the value obtained in simulations is a little bit too high (see figure 4a). This suggests that model assumed by

equation 7 is too simple and another deformation mechanism should be added, but the error committed due to this lack is not very big. The present model gives results of strain at failure in good agreement with experimental data. It was a drawback of previously used models and current model covering all creep stages yielded much better agreement with experiments.

tions and coefficients of variation (CV). Comparison of the coefficients of variation for all stress levels shows that the smallest one is for primary strain (from 4% to 21%), larger - for steady state creep rate (from 12% to 37%), and the largest for time to failure (from 23% to 43%). It suggests that the scatter of results grows with time during creep.

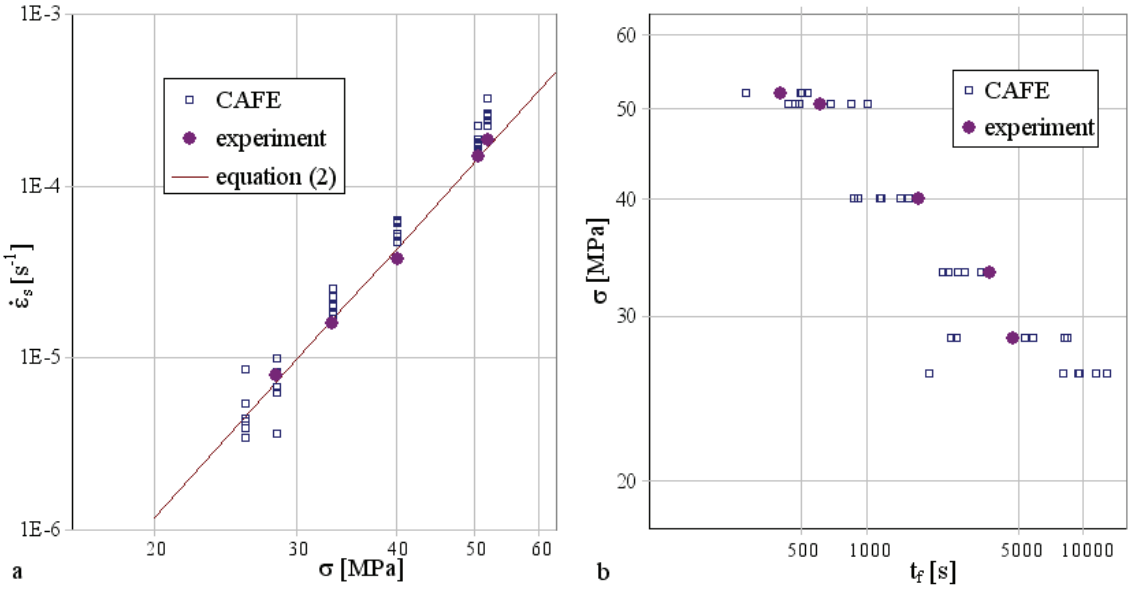

Fig. 3. Results of CAFE simulation for random initial structures (a) steady state creep strain rate (b) time to failure in function of applied stress in comparison with experimental points (Feltham & Meakin, 1959).

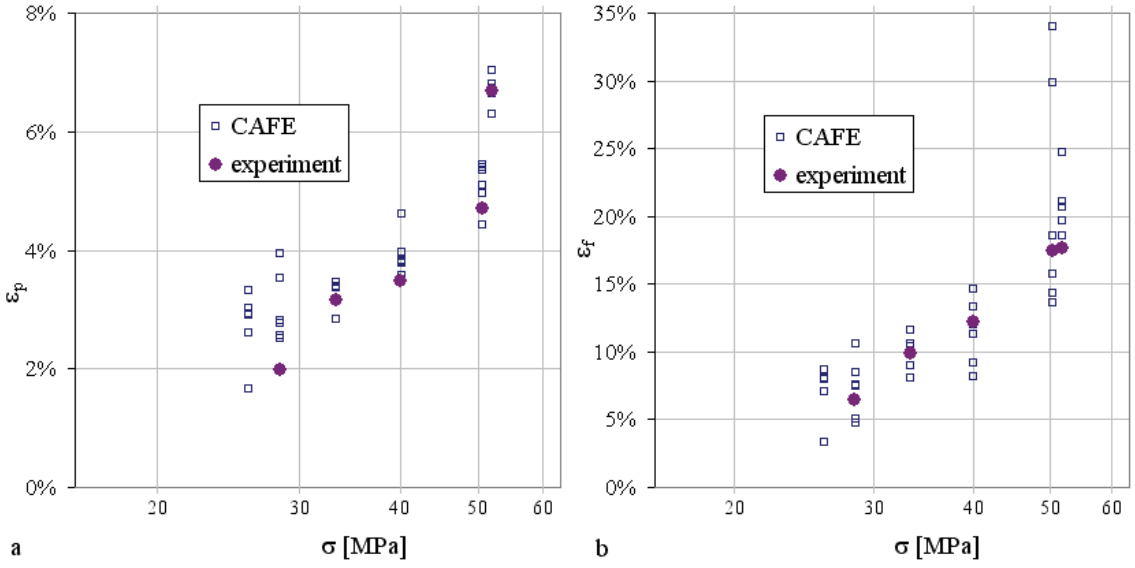

Fig. 4. Results of CAFE simulation for random initial structures (a) primary strain (b) strain at failure in function of applied stress in comparison with experimental points (Feltham & Meakin, 1959).

5.4. Analysis of results' scatter

As it was expected all analysed results exhibit a significant scatter. There are too few points (six) for a variable to determine the distribution function so the scatter was analysed on basis of standard devia-

The variability of time to failure according to the results presented in this paper is smaller than observed for small stress in experiment by Farris et al. (1990) on copper bicrystals (60%), but greater than that for larger stress in the same experiment (7%). For the small stress pure intergranular cavitation was

observed and in the case of higher stress the mechanism of failure was mixed. The CAFE simulation gives smaller scatter than in experiment due to idealisation of external condition not to be repeated in real experiment (for instance the problem of eccentricity). In CAFE simulation the scatter of results for higher stress is smaller than for small stress but not as small as in bicrystal experiment. The reason is lack of ductile failure modelling in present approach (only intergranular voids were modelled).

Additional simulations were run to compare scatter of results due to process of intergranular failure for the same initial structure. The results for 40.1 MPa show that the CV for time to failure (11%) is of about half of that for random initial structure. But the values of CV for the primary strain (11%) and steady state creep rate (13%) are of the same order. Similar results were obtained for 50.5 MPa. These results are intriguing because it looks that the process of damage development does not depend upon the process randomness, but only upon the structure randomness.

6. CONCLUSIONS

Performed simulations show that multiscale CAFE model can be a good source of information about the scatter of creep results - on macro level - provided that the randomness of material structure and mechanical processes is taken into account. The simulations, much cheaper than real experiments, can give results for wide spectrum of initial parameters. But to draw far-reaching conclusions the number of simulations has to be essentially increased. The CAFE model of intergranular failure gives good results for mean values and standard deviations if this mode of failure is prevailing. For larger stresses and consequently for different failure mechanisms, the model is well suited but only for the mean values of measurements; the scatter obtained in simulations happen to be too high in comparison with experiments and proposed model still requires further improvement.

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NIEJEDNOZNACZNOŚĆ OSZACOWANIA CZASU ŻYCIA DLA MODELU ZNISZCZENIA W WARUNKACH PEŁZANIA PRZY UŻYCIU TECHNOLOGII CAFE

Streszczenie

W pracy badany jest wpływ losowości mikrostruktury materiału na niejednoznaczność wyników doświadczeń obserwowanych w skali makro. Oczywiste jest, że na rozrzut wyników, szczególnie czasu życia konstrukcji pracujących w podwyższonych temperaturach, oddziałuje wiele różnych czynników losowych. Najważniejsze z nich to zmienność warunków pracy takich jak obciążenie i temperatura. Pomimo, iż mogą one być dość dokładnie kontrolowane w warunkach laboratoryjnych, rozrzut wyników doświadczeń jest także znaczny. Wynika on z losowości mikrostruktury materiału. Nie tylko czas życia struktury, liczony jako, czas do pojawienia się pierwszego makroskopowego defektu, ale też inne parametry, takie jak odkształcenie przy zniszczeniu, prędkość pełzania ustalonego mają charakter losowy. Do wykazania znaczenia struktury materiału został użyty model wieloskalowy, w którym wpływ polikrystalicznej budowy materiału na rozwój procesu rozwoju uszkodzenia został zamodelowany za pomocą automatów komórkowych. Rozważana struktura materiału jest jednorodna, wszystkie ziarna mają takie same właściwości oraz średnią wielkość. Zmienny jest kształt ziaren. Przeprowadzone symulacje wykazały, że otrzymany rozrzut czasu do zniszczenia dla zniszczenia międzykrystalicznego w warunkach pełzania jest tego samego rządu jak rozrzut wyników doświadczeń.

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