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# Remaining Creep Life Assessment Techniques Based on Creep Cavitation Modeling.

Kumar Ankit

Department of Metallurgical Engineering, Institute of Technology,
Banaras Hindu University, Varanasi, India
Phone: 0120-2402008, E-Mail: kumar.ankit.met05@itbhu.ac.in

**Abstract**
The boiler and its components are built with assumed nominal design and reasonable life of operation about two to three decades (one or two hundred thousand hours). These units are generally replaced or life is extended at the end of this period. Under normal operating conditions after initial period of teething troubles, the reliability of these units remain fairly constant up to about two decades of normal operation. The failure rate then increases as a result of their time dependent material damage. Further running of these units may become un-economical and dangerous in some cases. .
In the following paper presented, step by step methodology to quantify creep cavitation based on Statistical probability Analysis and Continuum Damage Mechanics has been described. The concepts of creep cavity nucleation have also been discussed with a special emphasis on the need for development of a model based on creep cavity growth kinetics.
**Keywords: Creep Cavitation, Cavity Nucleation, A-Parameter, Continuum Damage Variable ‘D’.**

## 1. Introduction

The importance of creep cavitation and its role in failure of critical components has been already studied in the past. However, there has been absence of a quantitative creep cavitation model which can effectively correlate creep cavities with the remaining life of the components. Efforts have been made in the past, but till now, the methods already developed have been able to provide only qualitative guidelines. This has been primarily because of two reasons. Firstly, due to lack of understanding especially, about the creep cavity nucleation, which is the least understood phenomenon till date and secondly, due to lack of a justifiable model that can correlate the surface cavities observed in the replica taken from in-service components to the creep cavitation occurring in the bulk, which obviously, is more representative of the creep life of the component. In the model that I am about to discuss, the creep cavitation has been beautifully correlated to remaining life using mathematical expression based on statistical probability distribution [1].
A remarkable achievement of the model is that it correlates the A-Parameter i.e., number fraction of cavitated grain boundaries observed on the replica with the Continuum Damage Variable ‘D’ which is area fraction of cavities present on grain boundary facets. The model makes use of Kachanov-Rabotnov Creep Damage theory and involves minimum mathematical calculations. The methodology of calculation is quite economical as the only experimental input required is the value of ‘$A_{cr}$’ (which is the critical value of A-Parameter at failure that can be easily determined by performing a hot tensile testing) as compared to creep testing and strain rate monitoring which requires expensive set up of creep machine and a diligent software to incessantly monitor strain rate which is very expensive at present.

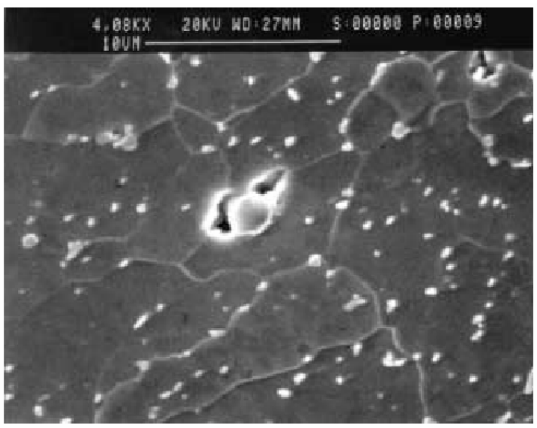
## *2.1 Factors Affecting Creep Cavity Nucleation*

*Creep cavity nucleation has been one of the least understood phenomena till date. The creep cavity nucleation rate affects the remaining life of a component. There are some rate laws which are specific to components and the grades of steel such as the relationship given below for the Type IV cracking in weldments:*

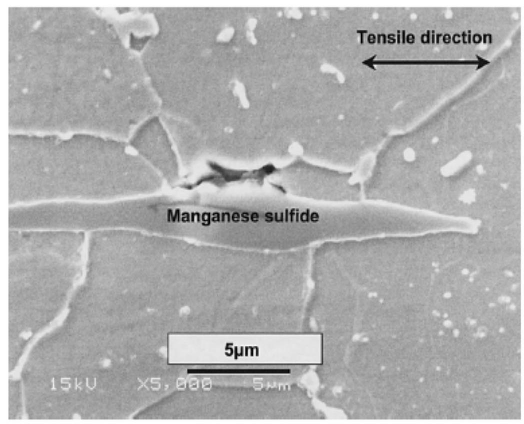
$$t_r = B\,\sigma^n \exp(Q/RT)$$ [3]

*where, B is the constant depending on the grade of steel, Q is the activation energy specific to grade of steel, R is the universal gas constant and T is the operation temperature in Kelvin. The extensive research work and literature survey has revealed the following facts.*

- *Presence of any non metallic inclusion or simpler words, any region that can act as a stress concentrator acts as initiators of creep cavities.*

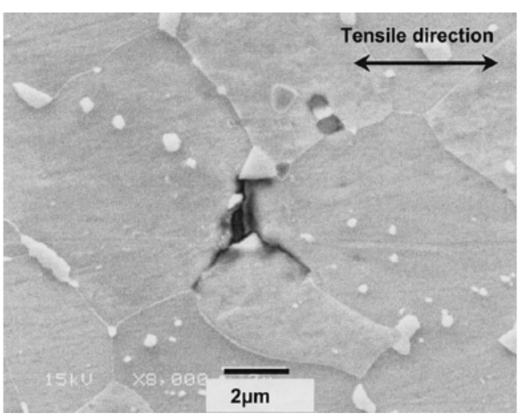


***SEM showing Cavity Nucleation at Non-metallic inclusions in the HAZ.***

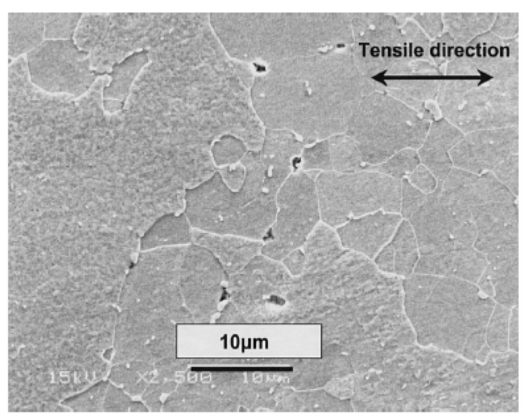



***Cavity nucleating at the interface of MnS.***

- *In absence of inclusions, the creep cavities generally nucleate at grain boundary triple points.*




***Creep cavity nucleating at grain boundary triple point***



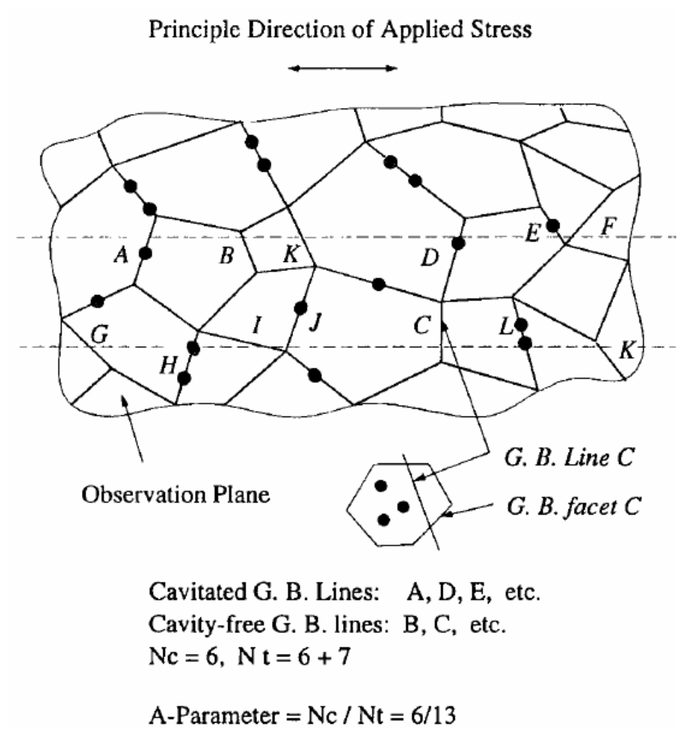

***Growth of creep cavities perpendicular to the stress axis***

- *The creep cavities generally grow and get linked up to each other in the perpendicular direction to the stress axis.*
- *The number of cavities per unit grain boundary area linearly increases with creep exposed time.*
- *As the amount of applied stress increases the rate of creep cavitation increases exponentially.*
- *High purity cast materials have the lowest nucleation rates and highest rupture life.*
- *Increase in austenising temperature leads to increase in nucleation rate and decrease in rupture life.*
- *Grain size and type of second phase particles such as carbides found on the prior austenitic boundaries increases the susceptibility to cavitations especially $M_2C$ carbides and SAE's i.e. surface active elements such as P and Sn.*

## *2.2 Steps for Quantifying Creep Cavitation*

### *2.2.1 Measurement of A-Parameter.*

*1. Divide entire replica (standard preparation as per ECCC recommendations [2]) into at least 400 parts by drawing reference lines parallel to the stress axis as shown in the figure below. The replica can be viewed at a comfortable magnification so that creep cavities are clearly visible. As the A-parameter is a ratio, the methodology rules out any ambiguity due to choice of magnification provided the number of reference lines is statistically high. The value '400' stated above is stated to ensure a minimum level of accuracy in calculation.*



*2. Calculate $N_C$ = Number of Grain Boundary lines that are cavitated intersecting the reference lines.*

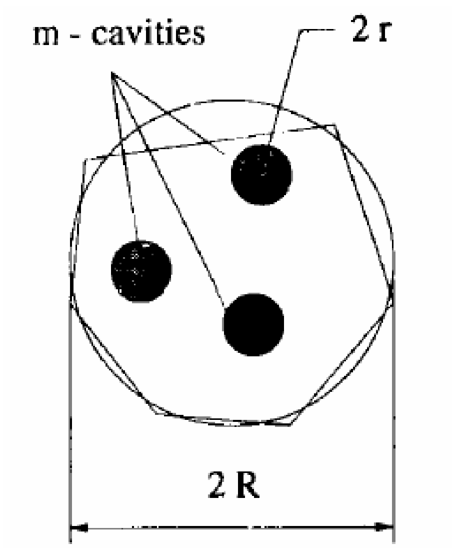
*3. Calculate $N_T$ = Number of Grain Boundary lines that intersect the reference lines.*

*4. A-Parameter = $N_C / N_T$*

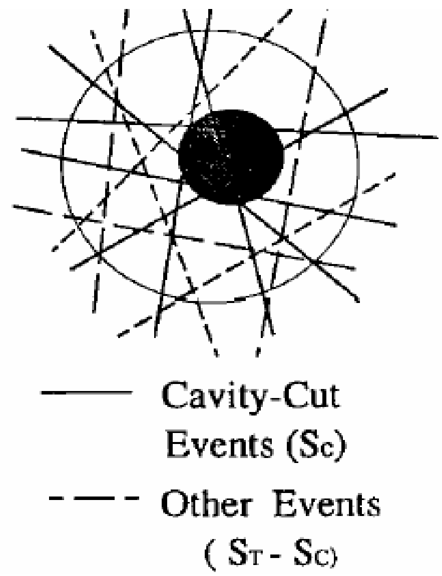
***2.2.2 Measurement of Cavity Cut Probability (P).***

*1. Prepare the microstructure from a destructive sample to expose the grain boundary facet. Isolate the grain boundary facet having maximum cavitations.*

*2. Draw a circle of area approximately equal to that of the facet. The circle is to be drawn around the facet shown below.*




***Grain Boundary facet with m-cavities on it and circle drawn around the facet [4]***




***Experiment to cut an idealized GB facet by a line from all the possible direction and position [4]***

*3. Draw lines through the cavities from all possible directions cutting the facet circle and cavity in the facet plane as shown in the figure above.*

*4. Isolate a cavity on the facet (all cavities assumed to be identical on a facet.*

*5. Calculate $S_C$ = event when line cuts the cavity.*

*6. Calculate $S_T$ = event when line is drawn through the facet circle.*

*7.* ***$P = S_C / S_T$.***

### *2.2.3 Measurement of Continuum Damage Variable 'D'*

*(1). Measurement of 'f' i.e. average number of cavitated facets.*

$$f = A / P.$$

*(2) Measurement of ω i.e. average local cavity area fraction on the facets.*

$$\omega = m (r / R)^2$$

*where, m = number of cavities on the most cavitated facet.*
*r = average radius of the cavities.*
*R = radius of the circle drawn around the facet.*

*(3) Measurement of Continuum Damage Variable 'D'.*

$$D = f * \omega$$

### *2.2.4 Determination of 'L' using A-D relationship*

*(1) Measure the value of A-Parameter at creep failure by performing a hot tensile testing and interrupting the test just before the failure of the sample.*

*(2) Calculate the value of $D_{cr}$ from $A_{cr}$.*

*(3) Determine $(D / D_{cr})$ and $(A / A_{cr})$.*

*(4) Put the values in the A-D relation given below:*

$$(D / D_{cr}) * [1 - (1 - D / D_{cr})^L] = (A / A_{cr})^2.$$

*(5) Calculate the value of 'L' from the above equation.*

*(6) **$L = n / (\lambda - 1)$**, where n = creep exponent for engineering alloy. $(3<n<10)$*
*and, $\lambda = \varepsilon_f / (d\varepsilon_{min}/dt * t_f)$.*

*(7) Calculate 'λ' as the value of 'n' is known for the given alloy.*

### *2.2.5 Determination of Remaining Creep Life*

*Remaining life of the components is given by:*

$$(1 - D / D_{cr}) = (1 - t / t_f)^{1/L\lambda} .$$

## ***Conclusion***

*There are a number of techniques that are available, at present to predict the remaining life of in-service components, both destructively as well as non-destructively. Out of these, prediction of remaining creep life has been an area of interest as the phenomena of creep is responsible for a majority of failures in power plants. The step by step methodology described above seems to be quite flexible, and can be easily incorporated into computer software such as MATLAB. To begin with, replicas can be taken from inspection sites followed by image processing of these replicas using Fast Fourier Transformations (FFT), i.e. filtering the image. In case, the replica taken is not very clear, the concept of fuzzy logic can be incorporated, The output obtained from image processing, such as A-parameter, inter-particle spacing, dislocation density etc can be fed into the equation mentioned above and remaining creep life can be calculated accordingly. The operating parameters such as the skin temperature of the component and stress is known so life estimation can be done effectively and that too, non-destructively which in itself is an added advantage. It does not involve any creep tests which are time consuming and expensive processes. The life assessment can be done on-site within a few minutes after the replica has been taken. Efforts are still on, to incorporate this methodology into more sophisticated computer software for more accurate life estimation.*

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