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A Study on the Cyclic Elastoplastic Performance of Aluminium 7075-T 6 Loaded in Symmetric Strain Control

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ABSTRACT

Creep and creep-corrosion, which are the most important degradation mechanisms in structures such as piping used in the nuclear, chemical and petroleum industries, in this paper have been studied maximum no of creep equation as well as identified, and further classified into two simple groups of power law and exponential models. Then, a probabilistic model has been developed and compared with the mostly used and acceptable models from phenomenological and statistical points of view. This model is based on a power law approach for the primary creep part and a combination of power law and exponential approach for the secondary and tertiary part of the creep curve. This model captures the whole creep curve appropriately, with only two major parameters, represented by probability density functions. Moreover, the stress and temperature dependencies of the model will be calculated. Based on the Bayesian inference, the uncertainties of its parameters have been estimated by Win-BUGS program. Linear temperature and stress dependency of exponent parameters are presented for the first time.

Keywords- Probability density function (PDF) ,Win-BUGS Program (WBP), Bayesian inference (BI)

Introduction

Creep is the occurrence of time dependent strain in material under constant stress, normally at elevated temperature. Creep occurs as a result of the competing processes of work hardening caused by the applied force (tensile or compressive stress) and of annealing due to high temperature. Creep usually attributed to vacancy migration in grains of bulk materials or along the grain boundaries in direction of applied stresses, (Nabarro-Herring, and Coble mechanisms), and causing grain boundary sliding and separation, and dislocation climb and cross-slip. Thermal power plants and refineries around the world share many of the same problems, namely aging equipment, high costs of replacement, and the need to produce more efficiently while being increasingly concerned with issues of safety and reliability. For equipment operating at high temperature, there are many different mechanisms of degradation, some of which interact with each other, and the rate of accumulation of damage is not simple to predict.

The principal deterioration mechanisms in high temperature plant are creep damage, micro-structural degradation, high temperature fatigue, creep-fatigue, hydrogen embrittlement, thermal shock, erosion, and high temperature corrosion of various types. Besides, although stress corrosion cracking and aqueous corrosion are not generally expected in high temperature components, they may cause problems during the components cooling while liquid is still present.

Creep is one of the most serious high temperature damage mechanisms. It involves time-dependent deformation. High temperature creep cracking generally develops in components that fail over an extended time such as boiler super-heater, petro-chemical furnace, reactor vessel components and gas turbine blades, and all other components operating at high temperature. In addition, local overheating at high temperatures may cause local deformation with large plastic strains and local wall thinning. In-service degradation with creep is one of the most critical factors determining the structural integrity of elevated temperature components in power plants, chemical plants, and oil refineries. Therefore study of creep, fatigue, corrosion and their effects on life time of materials subjected to high stress at high temperature is necessary. To investigate the pipeline health, risk and reliability, it is highly important to model creep and creep-corrosion phenomenon to characterize the observed deformation and fracture with respect to time.

The main Objectives of this paper are as follows:

1. To understand the Concept of Composites Materials, their nature and classifications
2. To study the concept of Creep Deformation, Diffusion, Fractures and Failures
3. To study the concept of Aluminum alloys and Carbon Steel
4. To study the formation and classifications of 7075-T6 Aluminum Alloys
5. To classify and develop a Probabilistic Model for Creep Failures of Structures

Literature Review

The term ‘literature review’ indicates a summary of the present bulk of research and investigation that has already been done on the domain. The review of the past work is most significant as it reveals the various contradictions of the opinions and the theories of the scholars, the shortcomings and the other problems that exist in the research work done so far. This is one of the best ways the direction and the quality of further research can be prescribed for a certain domain.

Pacholkova and Taylor (2012) It seems that the fracture procedures technique plays a very important role in the domain of pressurized components especially in the context of the pressure vessel's safe operations, storage tanks, and piping systems.

Dieringa et al (2015) have created the composites of a metal matrix in order to per come unsatisfactory performance in the context of high temperature creep conditions of alloys of magnesium that has been reinstated with the help of a small fiber of 20 vole% alumina

Fantozzi and Reynaud (2014) have created the ceramic matrix Composites or the CMCs for the purpose of the aeronautics applications because o their great mechanical characteristics at high temperatures. The scholars have stated that when the CMCs are exposed to a high temperature the fiber creeps failure may take place that can lead to a limited lifetime.

Ostsemin (2011) Generally speaking the fracture mechanics can speak of three variables - the

defect size, the toughness of the material and the stress that has been applied

Gomes et al (2011) investigated heat treatment of 7475 Aluminium alloy, specimens are heated in a solution at 520 deg for two hours was ineffective for homogenizing the matrix microstructure. At higher solution temperature 570 deg for 2 hours most of precipitates dissolved. The peak hardness was achieved only after ageing at 150deg for ten hours. These observations indicated that the composite precipitation kinetics was slower. The tensile specimens rupture occurred mainly through the A1/SiC interface.

Mohammad Zehsaz et al (2014) in this paper the influence of adhesive thickness and adhesive fillet on the creep deformation and creep life time of the adhesively bonded double lap joint have been studied experimentally. Also finite element modelling was used to simulate creep behaviour of bonded joints and the results are compared with those obtained from experimental tests. The adhesive used in this research was Araldite 2015 which is an epoxy based adhesive. Research procedure is carried out in two major stages. Firstly, uniaxial creep tests were conducted in 63 °C to obtain the creep characteristics and constitutive equation parameters of the adhesive at 63 °C. An empirical based rheological model based on Maxwell and Zener’s model is proposed to simulate the creep behaviour of the adhesive and it is used to predict the creep behaviour of the bonded joint using finite element method. Numerical results show good agreement with experimental data. It was observed that applying fillet increases creep life and decreases joint creep deformation, however increasing adhesive thickness has slight effect on the creep life time of the

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joint.

Basirat et al (2015) a dislocation-based creep model combined with a continuum damage formulation was developed and implemented in the finite element method to simulate high temperature deformation behaviour in modified 9Cr-1Mo steel welds, The creep tests were simulated in ABAQUS utilizing the developed numerical model. The modelling creep results show good correlations with the experimental results for the temperature range of 600–700 °C and stress range of 80 to 200 MPa. The model can be applied to study creep deformation and failure in three-dimensional complex geometries with different material propertie

Methodology

In this paper, intends to address in detail the issues related creep relations and classifications to develop a probabilistic model will be derive from a physics of failure approach. We have following steps

Step one: the general definition of creep and creep mechanisms from phenomenological point of view will provided. Besides, a classification of creep relations describing the creep curves is given together with the classification of creep models according to strain-time-, stress-, and temperature dependency; another classification is provided with respect to three parts of the creep curve.

Step two: a physically informed empirical model will be developed and justified in its comparison with the mostly used and acceptable models from phenomenological and statistical points of view. This model that based on a power law approach for the primary creep part and a combination of power law and exponential approach for the secondary and tertiary part of the creep curve captures the whole creep curve appropriately. Besides, stress and temperature dependencies of our model will be presented.

Step three: Various stress and temperature dependencies of parameters of creep model from published data are specified.

Then, the new probabilistic model will be validated by experimental data taken from Al-7075-T6 and X-70 carbon steel samples. The details of experimental designs of chambers for corrosion, creep-corrosion, corrosion-fatigue, stress-corrosion cracking (SCC) (to do the experiments both on CT and dog-boned steel and Aluminum samples), and a high temperature (1200 0C) furnace for creep and creep-corrosion (gas pressure) furnace both for CT and dog- boned samples will be provided.

Step four : practical applications of the empirical model to estimate the activation energy of creep process will be provided, and two case studies to estimate the remaining life of a super heater tube and probability of exceedance of failures at 0.04% strain level for X-70 carbon steel will be given

Data Analysis

. To complete creep experiments on Al-7075 and T- 6 a MTS machine is used which is available at the Maryland University. Thermometer of K-type is mainly used to adjust the sample temperature in the homemade furnace at the time of creep experiment.

Experimental Equipments Developed

Different types of chambers were designed for performing these experiments such as stress corrosion cracking (SCC), corrosion fatigue, corrosion and corrosion creep and in MTS machine. Their workability was checked. ALL these chambers are having enough potential to perform the experiments in different liquid surroundings from tap water to crude oils.

Also requirement of high temperature furnace mainly for creep experiments. This furnace has perfection for setting temperature of ±5°C.

Unique types of grips are needed for holding different types of samples from CT to dog bonesample were designed. All these grips can be cooled again with mainly designed coil from copper to prevent the transfer of heat to the MTS grips.

Below figure represent that the small and large scaled chambers designed for corrosion fatigue and tested for dog bone samples; its workability is basically checked in a corrosion fatigue experiment for an Aluminum prototype specimen

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Figure:1 The corrosion-fatigue chamber Below figure shows a complex test chamber for CT-samples which we basically designed and completely tested. This chamber is mainly used for stress corrosion cracking tests of Aluminum and X-70 carbon steel CT-specimens

Figure:2 The heating chamber

Sample Preparations and Accompanied Problems

There are about two types of specimens for performing the experiments on: Aluminum 7075-T6 and X-70 carbon steel were manufactured as follow

Al-7075-T6-Samples

For performing creep experiment, Aluminum 7075 dog-bone specimen were manufactured. Below figure shows these samples with their suitable stainless holders for fixing them in the furnace; the holders are mainly installed in the grips of the MTS machine for transferring heat.

Preliminary Creep Experiments with Al-7075-T6Alloys

Resistance and creepiness of material is basically related with time dependent plasticity of materials over a consistent and continuous strain at an highest temperature, many times greater than near about value (0.4 to 0.5) T_m, where T_m refer to the absolute melting temperature. For completing the creep experiments, there are 2 various types of materials which were considered –

a) Al 7075-T6
b) X-70 carbon steel

The primary creep experiments were performed on the specimens of Al 7075-T6 due to its requirement of lower temperature in comparison to X-70. Properties of reliability of tools were checked under the various load and displacement conditions at various temperatures. For calculating the amount of consistent and continuous strain executed to the specimen, curve of stress strain of all thesematerials was also used.

The curve of stress-strain for Al-7075 and its counterpart from the review of literature are given in below figure:

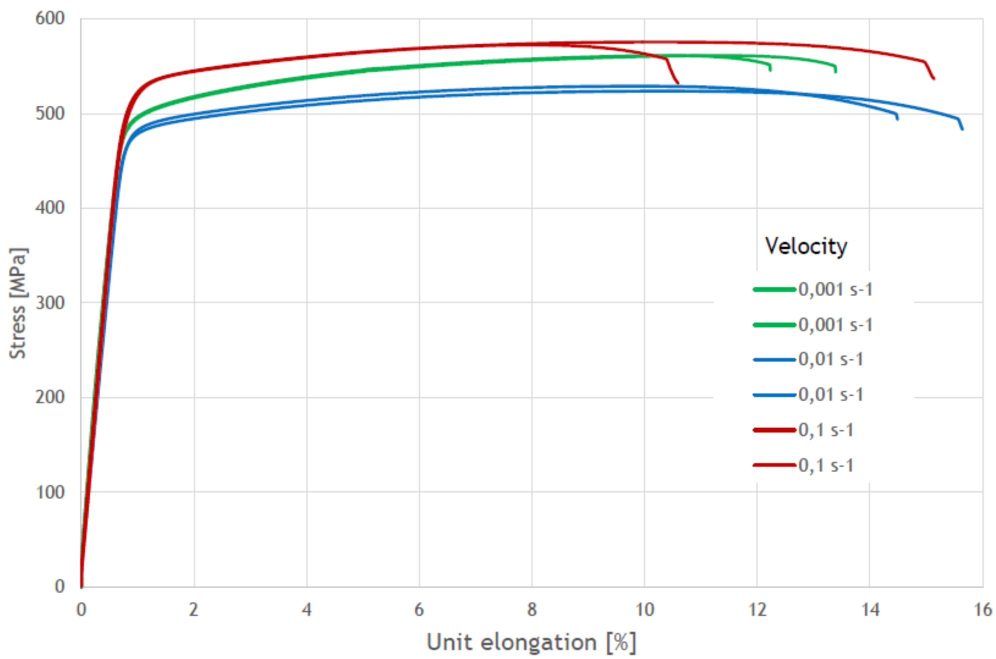

Figure:3 Stress-strain curve of Al-7075-T6 alloy left , and stress-strain curve of the same alloy.

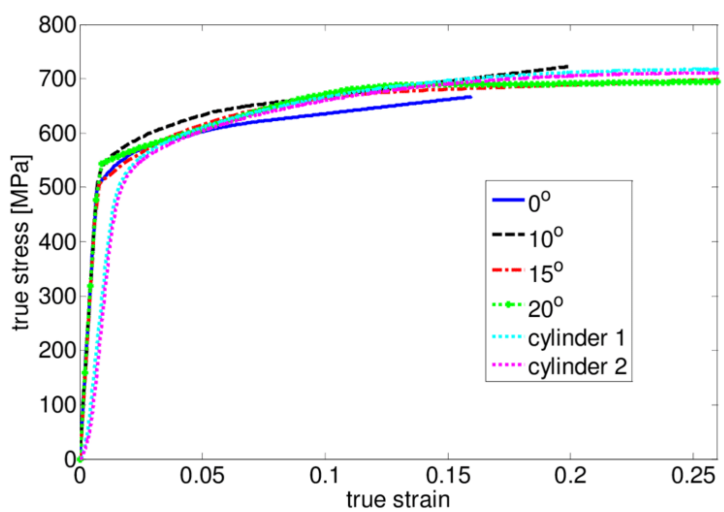

Figure:4 MTS Displacement vs. Time for Different Al-7075-T5 Alloys at Different Stresses

Dependency of coefficient A, Stress, exponent n and a, of the empirical equation for the primary part determination, are given by the following relation:

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$$\mathbf{A=\alpha a^{m} \quad \text{and} \quad n= \beta\alpha + \gamma} \tag{1}$$

with:

$$A=4\times10^{-7}a^{2.5123}\text{and } n=-0.0003\times a+0.1809 \tag{2}$$

Here, α, m, β, and γ are refers to the parameters of the materials that perhaps rely on the temperature and ether various parameters of materials.

The conclusive stress relying on creep equation seems like:

$$S = 4\times10^{-7}\cdot a^{2.5123}\cdot t^{-0.0004\times a+0.1811}+ [B\ t^{N}\ \exp(et)] \tag{3}$$

Extra experiment was mainly done on a specimen of Aluminum. This creep experiment basically enables the analysis of the secondary and tertiary creep. The outcomes of this creep experiment are representing in below figure.

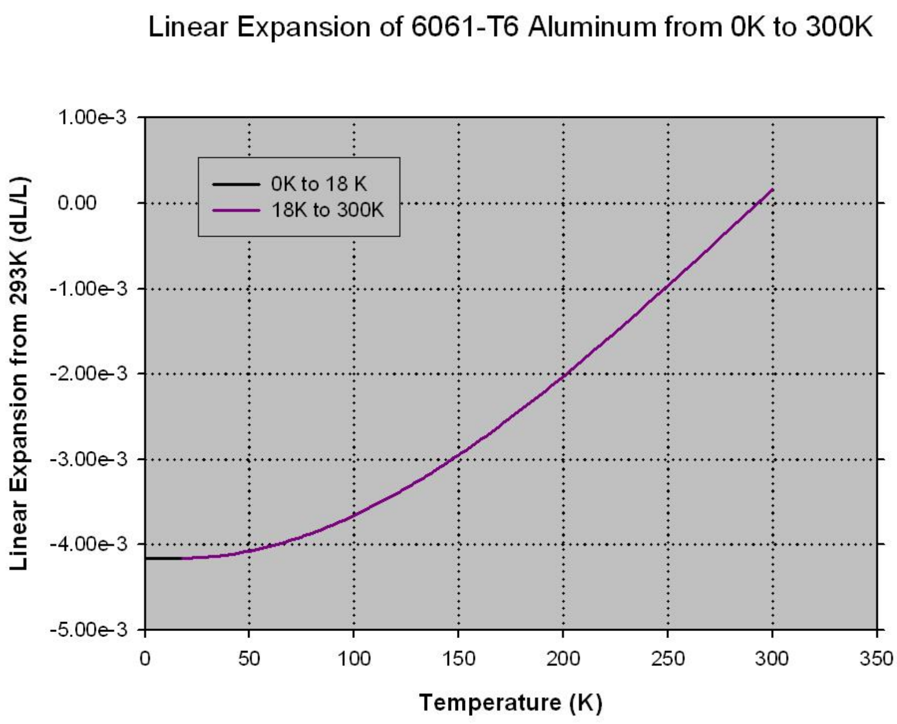

Figure:5 Displacement-Time (creep curve) of Al-7075-T6 at 400°C

The below relation was attained for the creep attitudes by an executed force of 19000 N, at 673K temperature:

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$$s=0.000685t^{O.939}+(1.670\times10^{-8})t^{1.965}\exp(0.000775t) \quad (4)$$

That is how we have calculated stress equations as per various conditions. Now we will calculate all constant parameters for proposed modal

Formed empirical model had the following form and the consistent parameters values are basically given the below table.

$$s=A\cdot t^{n}+C\cdot t^{N}\cdot \exp(e\cdot t) \quad (5)$$

where A, n, B, m, and p are material parameters and depend on temperature and applied stresses.

Table:1 Numerical values for corresponding parameters of the proposed empirical model

T (◦C)	T (◦K)	σ (MPa)	A	N	B	m	P
406	679	462	0.000157	0.771898	1.87789E-13	1.3319 878	0.00075
416	690	482	0.000199	0.775726	1.77525E-11	1.4668 997	0.001576
419	693	495	0.000210	0.68987	4.31998E-10	1.5467 990	0.002545
431	705	522	0.00255	0.786342	1.7689E-07	1.6829 090	0.007809

So, it was possible to calculate the parameters of temperature and stress dependencies. Parameters A, B, and p have exponential parameters dependencies on stress and temperature.
n and m have a linear parameter dependencies on stress and temperature.

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Exponential parameter dependency on temperature for parameter A is known in the creep literature but essential linear parameters dependencies of n and m values on stress and temperature are mainly shown for the first time. All parameters were calculated by excel and distribution for A and other parameters by mat lab program, showing creep curves bt MATLAB .General relations were look like.

$\boldsymbol{\varepsilon = At^{n} + Bt^{m} \cdot e^{(p.t)}}$

With A =4.1255E7. exp (-0.0069. σ) . exp (-142000/RT$_1$)

Similer steps we done for X 70 carbon steel and similer equation has been found which is as same as creep equations.

Results

As we have calculated various parameters of alloy aluminium and carbon steels, like stress displacement curve , stress strain curve with various loads and various tempreture values we have developed and empirical modal verified by matlab , which gives the same equation as creep occure.So at last we can say that linear modal gives primary creep and as we increasing the the tem wrt to time we are getting secondary and tertiary creep.

Discussions

In this study we have found the modal which is similar to the creep failure . creep failure is very much important for pipelines and time dependent phenomena. So this is how we can calculate the approximate creep curve of failure of various pressure vessels and that is how we can reduce the failure time.

Conclusion

The proposed modal is simple and consist of only two parameters. Linear temperature and stress dependency of exponent parameters n and m presented here for first time. First time particular modal has been developed to calculate the exact life of pressure vessels. all parameters like stress, strain, temperature, displacement were calculated and distributed as per given conditions. And all equations were verified by matlab for given conditions.

$$\varepsilon = At^{n} + Bt^{m} \cdot e^{(p.t)}$$

Limitations and Future Studies

Due to lack of time creep time that we we used can be more long. We have verified only three samples with max 4 no of loads,so in future study we can use WinBUGS program for more statistical analysis using Bayesian inference so that we have more number of sample space and more exact values of parameters.

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