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SIMULATION OF THE SMALL PUNCH CREEP TEST WITH CONSIDERATION OF VARIATION OF MATERIAL PROPERTIES

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ABSTRACT

A new finite element model of the small punch creep test is described. The material constitutive relationship for creep considered is a simple Norton power law: in this study the exponent in the power law is varied for each element to simulate the random behaviour of creep. The influence of this random variation, and the effect of the friction factor between the punch and specimen, on the deformation and stress field has been investigated.

1 INTRODUCTION

Creep is a slow unrecoverable deformation procedure and can cause extreme problem for in-service components, for example, the large creep deformation of turbine blade under the high temperature and long duration will lead to the contact of blade with casing and this can damage the turbine. The make a good creep design and life prediction of structure and component, the material creep behaviour must be studied. The scatter of material creep properties is a widely known phenomena, this may be caused by the non-uniformly distributed material chemical composition, different grain size and different grain boundary shape and also heat treatment. Material manufacturing process such as rolling and forging can further increase the range of the scatter. Standard tensile creep test has been used to obtain the value of material creep parameter for many years. Small punch test technique was used for creep test at the early 1990s. This technique was initially used to obtain the unclear reactor material properties and late be used to determine Young's modulus, the material fracture toughness, the ductile-to-brittle transition temperature, yield stress and ultimate tensile stress, true stress and plastic strain curve, etc.[1-3] The main advantage of small punch creep test over standard creep test is that only a modest amount of material required for testing. This is especially important for the assessment of the properties of the in-service component for no repairing such as welding is needed after sampling. With the research effort on SPT technique over the past decades, a code of practice for small punch creep testing has been set up in European and some other countries.

Although D.G. Harlow and T.J. Delph [4] presented a computational probabilistic model for creep-damaging solids analysis, for the previous researches on small punch creep test, the scatter of creep properties has been completely ignored. In this paper, a finite element model of small punch creep test is presented. The Norton law creep constitutive relationship has been employed with the power index varying with a small random value from the mean value. The finite element model for simulation is given in the section 2, and the numerical results are presented in section 3, final section is the conclusions and discussions.

2 FINITE ELEMENT MODEL

The geometrical model of small punch creep test is shown in Figure 1. The model consists of an upper and a lower die, a punch and a specimen. The specimen is a thin circular disc with diameter of 8mm and thickness of 0.5mm, while the punch radius is 1.25mm. The inner diameters of upper and lower die are all 4mm. Both the upper die and bottom die has a fillet radius of 0.2mm. To reduce computational CPU time, axi-symmetrical model with rigid punch and dies are used. The material of the specimen is assumed to obey the Norton law. The Norton law constitutive equation is as following

$$\dot{\varepsilon} = A\sigma^n t^{-m} \quad (1)$$

Where A is the coefficient, n is power law index and m is time related constant. To consider the scatter of material properties, power law index n for each element is its mean value plus a small random value, while the value of the coefficient A is kept constant. In this paper, the first stage creep is not considered, so the value of m is set to zero. The A=2.261*10^{-21} is used in the paper, the unit for stress is MPa and time unit is hour. ABAQUS commercial finite element codes are employed for the simulation. The penalty form is used for the contact analysis and the friction factor between the punch and specimen may vary for different cases. The friction factors between dies and plate are assumed as 0.3 for all simulation through the paper. Four node axi-symmetry quadratic elements with reduced integration are used. The bottom support die is fully fixed at its rigid body reference point, and the upper die is also constrained. The applied force on the punch is 100N. Due to the contact between the punch and the specimen and also the dies and the specimen, the plasticity step is required to obtain a reasonable stress for the elastic step may induce too high stress within the contact areas,

3 SIMULATION RESULTS

In this section, first the influence of friction factor between the punch and specimen contact surface on the specimen deformation is studied, while keeping the material parameters unchanged. Then, the investigation of the scatter of creep power law index n on the deformation and stress field of the specimen is performed, while assuming the contact surface friction factor as constant. Final test case is the same as the second case, but the friction factor between the punch and the specimen varies.

3.1 The influence of friction factors under constant material parameters

Figure 2 shows the variation of the displacement at the specimen central point with the friction factors at different time. The power index n of 8.25 is used for this case. Assuming the factor between the upper die and low die with specimen is fixed as 0.3 while the friction factor between punch and specimen varying from 0 to 0.5. From this figure, it can be seen that the larger the friction factor, the smaller the central displacement. The relative difference of the central point between frictionless and friction factor 0.5 are changing with time. The longer the time, the larger relative difference will be. The relative difference of central point displacement between the case of f=0.0 and f=0.5 is about 15%. For small punch creep test material characterization, the central point displacement curve or punch head displacement is used to obtain material creep properties, the surface contact condition must be studied.

3.2 The influence of material parameters fluctuation

To consider the scatter of material creep parameters, a small random value plus mean value of n is assigned to each element. Figure 3 shows distribution of the n value within the model. For this case, the friction factor f between punch and specimen is 0.1, and the mean value of n is 8.25 and the range of the random number is 0.5, so the minimum and maximum value for n will be 8.0

and 8.5 respectively. The ratio of the maximum and minimum *n* value to its mean is about 6% (0.5/8.25*100%). Figure 4 shows the Von-Mises stress contour on the deformed specimen shape. The same results for the uniform material properties are shown in Figure 5. By comparing these two figures, it can be seen that the maximum stress is different for the two cases, with the later one has smaller maximum stress values. The relative difference between the maximum stresses is about 9.4% and is bigger than that of relative difference of *n*. From Figure 4, the inhomgeneous deformation and stress field for the model is obvious. By investigating the final displacement(at time t=4.32e5h) along the specimen bottom surface for the two cases, the average difference is about 2.5 microns, with a maximum difference of 7 microns. The requirement of displacement transducer repeatability for small punch creep test is 1 micron. Due to the specimen thickness is only 500 microns, and the final central point thickness is much smaller, this difference has to be considered.

3.3 The influence of friction factor under the fluctuation of material parameters

For the above model with the scatter of material creep properties being considered, the cases of friction factor between punch and specimen of 0.1 and 0.5 are investigated. The final displacement(at time t=4.32e5h) at specimen central point for f=0.1 is 1.308mm, while for f=0.5, it is 1.182mm. The relative difference is 11%. This means that the friction can play a very important part on small punch creep test with the consideration of material scatter.

4 CONCLUSIONS AND DISCUSSION

The main purpose of this paper is to show the important factors on the deformation and stress field of the specimen by the punch test. The surface contact properties and the scatter of the material creep parameters have been investigated by FEM simulation. From the above simulation results, following conclusions can be drawn

(1) The surface contact properties between the punch and the specimen can have a bigger influence on the deformation of the specimen. The relative difference can reach 15% between the cases of the frictionless and friction factor of 0.5.

(2) The finite element models of the constant material properties and material properties with scatter have been performed. The relative difference of maximum Von-Mises stress between two cases is lager than the ratio of power index *n* range over its mean value. The inhomgeneous deformation pattern is observed.

Discussions:

For material creep properties characterization by using small punch creep experiment results, two main methods are used, the first one is the theoretical solution of Chakrabarty membrane-stretch model, with the friction between the punch and the specimen is ignored, another one is the using of finite element method, but normally the friction factor is just given an assumed value. Due to the big influence of friction factor on specimen central point displacement, an exact friction factor must be obtained for a better prediction of the material parameters. Therefore, friction behaviour between punch and specimen should be performed.

Future work will be the addition of the third stage creep damage into this model and the creep material characterization involving the determination of the mean value and also the range of its variation.

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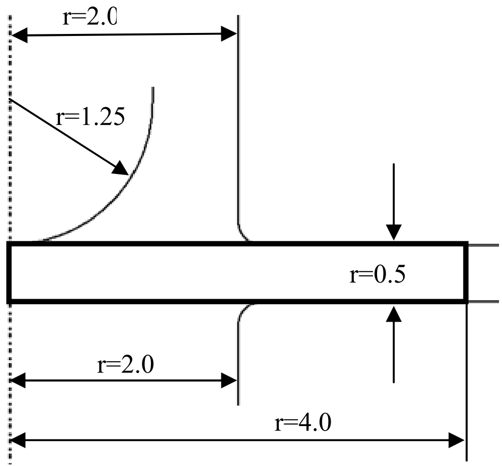

Figure 1 Small punch creep test model, unit: mm

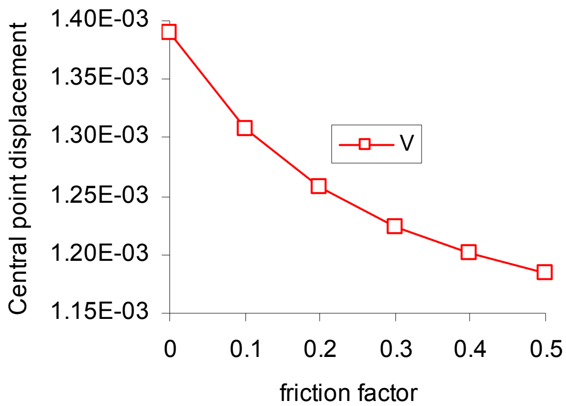

Figure 2 Central point displacement (unit: m) varies with friction factor.

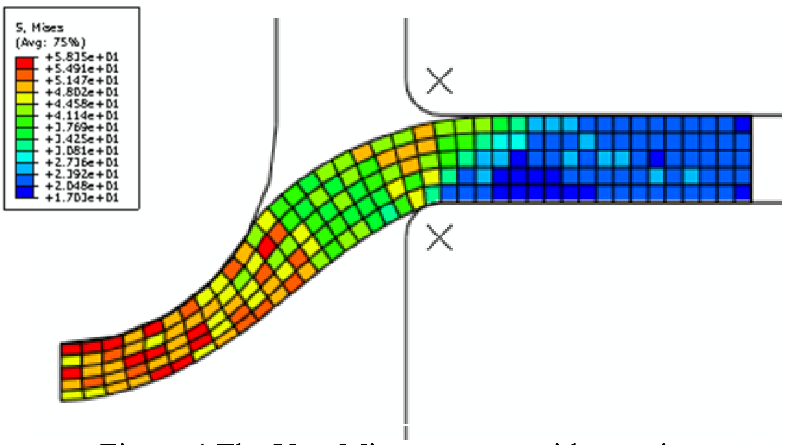

Figure 4 The Von-Mises contour with *n* varies from its mean value and a small random value

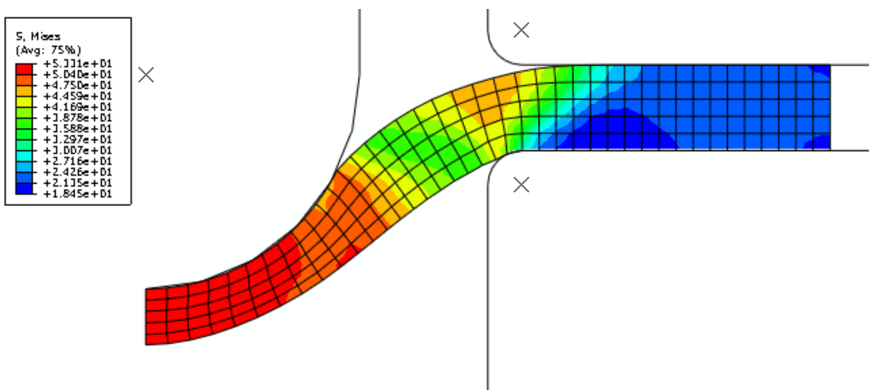

Figure 3 The power index *n* value varies at different material points

Figure 5 The Von-Mises stress contour with constant *n*