

Study on the Role of Strain Rate in Plastic Deformation

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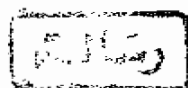
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TO MY PARENTS,

WITH LOVE AND GRATITUDE



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Summary

A Finite Element program (Code No. 1) was initiated for calculation of nonuniform elasto-plastic deformations to simulate upset forging problems, using 9-nodes isoparametric quadrilateral elements with 3×3 GAUSSIAN integration order, taking into consideration the non-linear plastic behaviour with strain hardening, the effect of strain rate sensitivity and deformation heat and its influence on the mechanical behaviour.

This program was made to deal with plane stress, plane strain and axisymmetrical problems using an iterative procedure for the nonlinearity. The boundary conditions for upset forging problems are simulated as applied stresses or displacements. It was found that the most influencing factor for the bulging profile in upset forging is the external friction which was modelled as a proportional friction.

An experimental study was made to compare the results with the values predicted by the computations. These experiments, including the determination of the material flow curves consist of upsetting the specimen under different frictional conditions.

On the other hand another Finite Element program (Code No. 2) was written and modified to be applicable for high strain rate deformation problems and calculation of plastic wave propagation. Application examples for the study of the effect of plastic wave propagation were done [Central Library - Ain Shams University](#) with different lengths and for

a free moving cylinder with a semisphere end using SEEGER and linear models.

In order to ensure the theoretical consideration, experiments were carried out on cylindrical specimens with different height-diameter-ratios, which were impacted by falling hammer using lead foils as lubricating layers. The non-uniformity of the deformation distribution in the impacted specimens was found to have similar forms as those expected from the finite element models.

Introduction

Strain rate sensitivity of materials has been major subject of concern for all involved with metal working processes, particularly in recent years with the development of high energy rate forming processes which result in great plastic deformation at high strain rates. Therefore it has become essential firstly to know to what extent materials are sensitive to strain rate and secondly to estimate the strain rates involved accurately enough in any particular metal forming operation so that necessary provisions can be made for designing tools and equipment. The Finite Element Method (FEM) is considered as one of the most powerful calculation techniques which was originally developed for problems in structural analysis and is now used in many applications among which are also metal working problems.

The objective of the present study is to predict the mechanical behaviour of materials under quasi-static and dynamic loading taking into consideration the different constitutive equations which relate the flow stress to the strain, strain rate and temperature. In chapter one the boundary value problems are classified into time independent problems and time dependent problems. The first type is usually known as equilibrium steady state problems and the second as propagation or transient problems. The different methods to solve these problems are discussed and the basic formulations for the FEM are explained.

As applications chapter two deals with the first type and chapter three deals with the second type. In chapter two a Finite Element program is introduced to simulate upset forging. The flow curve of Al 99,98 has been experimentally determined and the flow curve of

steel X 12 CrNi 20 12 has been evaluated. Both flow curves are implemented into the program to predict the deformed mesh and effective stress, effective strain, radial strain, tangential strain and temperature increase distributions during deformation with different reduction ratios. Comparisons between experimental results and FEM predictions are also shown.

In chapter three another Finite Element program is used which was modified to deal with different constitutive equations which describe the material behaviour under strain rates up to impact and shock wave conditions. The strain and strain rate distributions at various times are calculated using SEEGER- and linear models. An experimental determination of the deformation distribution has been done for Al 99,98 cylinders with different heights under different frictional conditions, using a falling hammer.

The general conclusions are collected in chapter four.

1 Finite Element Formulation

The finite element method has been first presented in 1956 by TURNER, CLOUGH, MARTIN and TOPP /1/, applying simple elements (pin-jointed bar and triangular plate with inplane loads) for the analysis of an aircraft structure and representing one of the key contributions in the development of the finite element method. The digital computer provided a rapid means of performing the many calculations involved in the finite element analysis and made the method practically viable. Along with the development of high speed digital computers, the application of the finite element method also progressed at a very impressive rate. The survey paper by ODEN /2/ summarizes some of the important mathematical contributions to the finite element method. ZIENKIEWICZ and HOLLISTER /3/ presented the finite element method as applied to the solution of stress analysis problems whereas ZIENKIEWICZ and CHEUNG /4/ presented the broad interpretation of the method and its applicability to any general field problem.

Over the years several papers, conference proceedings and books have been published on this subject /5-25/. Although the finite element method was developed originally for the analysis of aircraft structures, the general nature of its theory makes it applicable to a wide variety of boundary value problems in engineering. A boundary value problem is one in which a solution is sought in the domain of a body subject to the satisfaction of prescribed boundary conditions on the dependent variables or their derivatives.

In the last years the finite element method has become one of the most important methods used to predict the mechanical behaviour of engineering materials under service conditions. The increasing demands to higher safety especially involved with nuclear reactor design made the application of accurate calculation methods over very wide ranges of loading conditions of the materials an essential request for giving the working allowance of reactors. Therefore the finite element method was essentially modified and extended to deal with material loading problems which differ over a wide range of strain rate starting from creep up to impact and shock wave propagation under temperatures varying up to 0,6 of the melting point.

The two major categories of boundary value problems which are especially interesting in production and engineering are:

- i) Equilibrium steady state or time independent problems. In these problems it is usually needed to find the steady state displacement of material points or to determine stress distributions.
- ii) Propagation or transient problems which are time dependent. This type of problem arises, for example, whenever the response of a body under time varying forces or moments is to be determined.

1.1 Solution of Equilibrium Problems

The governing finite element equations for the equilibrium problems can be expressed as follows

$$[K] \vec{d} = \vec{F} \quad , \quad (1.1)$$

subjected to the boundary conditions

$$[A] \vec{d} = \vec{Q} \quad (1.2)$$

in which $\vec{d}$ is the vector of unknowns, $\vec{F}$ and $\vec{Q}$ are vectors of known constants.

$[K]$ and $[A]$ are matrices of second order.

$$\begin{matrix} \vec{d} \\ (nx1) \end{matrix} = \begin{Bmatrix} d_1 \\ d_2 \\ \vdots \\ \vdots \\ \vdots \\ d_n \end{Bmatrix} ; \quad \begin{matrix} \vec{F} \\ (nx1) \end{matrix} = \begin{Bmatrix} F_1 \\ F_2 \\ \vdots \\ \vdots \\ \vdots \\ F_n \end{Bmatrix} \quad (1.3)$$

$$[K]_{(nxn)} = \begin{Bmatrix} K_{11} & K_{21} & \dots\dots\dots & K_{1n} \\ K_{21} & K_{22} & \dots\dots\dots & K_{2n} \\ \vdots & \vdots & & \vdots \\ \vdots & \vdots & & \vdots \\ \vdots & \vdots & & \vdots \\ K_{n1} & K_{n2} & \dots\dots\dots & K_{nn} \end{Bmatrix}$$

The methods available for the solution of large systems of equations can be divided into two types: direct and iterative.

1.1.1 Direct Approach

Eq. (1.1) represents a system of n linear equations which