STUDIES IN FORGING AND EXTRUSION OF TOOTHED ELEMENTS

BY

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CERTIFICATE

This is to certify that the thesis entitled, 'Studies in Forging and Extrusion of Toothed Elements', being submitted by Shri Om Parkash Grover to the Indian Institute of Technology, Delhi for the award of the Degree of Doctor of Philosophy in Mechanical Engineering, is a record of bonafide research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which has reached the requisite standard.

The results contained in this thesis have not been submitted in part or in full, to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Toothed elements, like other parts, can be more economically manufactured by forming through forging and extrusion processes than by the cutting processes. The forming processes also result in improved structural properties of the product. The analysis of such operations are likely to improve the design of metal forming equipment. In this thesis, analysis of close die forging of some complicated shapes such as splines, gears, milling cutters, square discs with protrusions located diagonally and at middle of sides and polygonal discs with similar protrusions have been attempted. Attempt has also been made to study the extrusion of radial splines. All these analyses which pertain to rigid plastic materials, obeying von Mises' flow rules, are based on upper-bound techniques.

The first chapter which forms the introduction to the thesis, gives the literature survey on the solutions of problems of forging and extrusion processes. It also gives a survey on the nature of friction at the interface between dies and work material, idealization of material properties in plastic flow and upper-bound technique.

Splined parts can be produced by forging or by extrusion. The analysis of forging of splined parts in closed and semi-closed dies is given in the second Chapter. In the first case,

the die has closed spaces with entry gates at the periphery of a hollow core and the punch is circular in shape. As the punch compresses the billet, the material flows into the spaces provided at the periphery. In the second case, the punch has protrusions corresponding to the spaces in the die. The die and the punch fit each other in operation. With the downward movement of the punch (the die being held stationary) the material in the circular core region as well as under the protrusions (spaces) gets compressed. A kinematically admissible velocity field based on the observations of experiments conducted on lead specimens marked with circular and radial grids, has been assumed. Based on this velocity field, the rate of work of deformation, the power dissipation in friction on tool-work interfaces and on the surfaces of velocity discontinuity have been calculated. The variation of relative average pressure i.e. the ratio of average punch pressure to the yield stress has been studied in relation to various parameters such as (i) t/d (ratio of length of splines to diameter of shaft, (ii) magnitude of interface friction and (iii) the number of splines. The value of relative pressure has a minimum when the number of splines is about six, however, it varies with the value of friction factor.

The process of forging of gears is gaining importance because it gives the advantage of improved strength, better surface finish and is more economical as compared to conventional techniques of gear cutting. The third chapter deals with the analysis of forging of gears. Since the gear geometry is quite complicated, some simplifying assumptions are made. The gear teeth are considered straight instead of the involute or cycloidal profile. The velocity field has been based on the experimental grid deformations. The effect of changing various parameters i.e. the number of teeth, t/D ratio (face width to diameter) and interface frictional stress on the relative average punch pressure has been calculated by considering involute addendum and dedundum sizes with 20^{o} pressure angle. The root thickness (the deciding factor for strength) has been approximately taken same as for the the actual 20^{o} pressure angle. The simplified gear geometry is approximately true for finer modules and large number of teeth. Excluding the teeth with undercutting, the solution is thus valid for 20 or more number of teeth. However, there may be some differences due to gear geometry for small number of teeth. The calculations show a minimum of relative average punch pressure between 20-30 teeth.

The forging operation used for getting rough shape of milling cutters would economise their manufacture. The exact profile of cutting edges is obtained by grinding operation. In Chapter four, the above analysis of gear forging is extended to forging of milling cutters the cutting edges of which have one face radial and the other inclined. The effect of different parameters i.e. t/D, number of cutting edges and interface friction has been studied. It is found that the relative average punch pressure decreases with higher values of t/D to a nearly constant value.

The shape of many forged elements like cross-piece, spider, rotor of some pumps, lever with central boss, parts with large number of splines, etc. can be approximated to those of polygon discs with protrusions. The fifth Chapter deals with the analysis of forging of polygon discs with protrusions from circular billets in a closed die forging operation. The detailed calculations have been done for square disc with diagonal protrusions. A kinematically admissible velocity field has been formulated. The effect of various parameters - t/D ratio, and interface friction has been studied.

The analysis of extrusion of radial splines has been done in the sixth chapter. Instead of considering a dead zone, a deforming zone similar to unit deforming region has been considered. The material flow in the region above the die tooth has been assumed to satisfy the boundary conditions with the adjoining deforming regions. The axial velocity component in this region has been assumed to reach zero value at the die tooth surface over a height h, while it is increasing in the other regions. Kinematically admissible velocity fields have been taken in different deforming regions. The operating (optimum) value of 'h' has been found by minimizing the relative average pressure (extrusion load). The effect of varying the number of splines and interface frictional factor on h and punch load has also been determined.

The last Chapter seven, gives the broad conclusions reached at in different chapters of this thesis. It also gives suggestions for extending the present work to other practical problems of forging and extrusion.

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