A THESIS ON
MECHANICS OF AXISYMMETRIC
CLOSED_DIE COLD FORGING PROCESS

BY

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CERTIFICATE

This is to certify that the thesis entitled 'Mechanics of Axisymmetric Closed-die Cold Forging Process' by Shri Prem Chand Sharma has been prepared under my supervision in conformity to the rules and regulations of the Indian Institute of Technology, New Delhi. I further certify that the thesis has attained a standard required for a Ph.D. degree of the Institute. The research report and the results presented in the thesis have not been submitted for any other degree in any other University.

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SUMMARY

The present study is concerned with an accurate analysis of the closed-die cold foring process. A detailed literature survey (Chapter 1) showed that the available methods of analysis for the process are based on highly simplifying assumptions regarding the behaviour of the material and the mode of deformation. The closed-die forging process involves finite strains and both material and geometric non-linearities are encountered. If one has to discard the simplifying assumptions and use the rigorous theory of plasticity, then, under the above mentioned conditions, a closed form solution to the problem is not possible. As a result, numerical techniques were thought to be the only feasible way out for tackling this problem. Two computer programs based on the two numerical methods, namely, the Finite Difference Method and the Finite Element Method, have been developed for this purpose. Both the material and geometric non-linearities have been fully incorporated in the analysis based on the above two numerical methods. A sequentially updated Lagrangian formulation has been adopted in both the numerical methods. Inertia and temperature effects have been neglected and the process has been treated as quasi-static. The infinitesimal incremental plasticity theory has been adopted with the assumptions that the total incremental deformation measure is the sum of its elastic and plastic components. von Mise's

yield criterion is used alongwith the associated flow rule, that is, the Prandtl-Reuss equations. Isotropic hardening has been assumed as it is a good model for quasi-static process and also because this a ssumption is advantageous in respect of the computational time and computer storage requirements.

Next, in Chapter 2, the model of the closed-die forging process and the basic method of solution have been described. The incremental problem is formulated and the governing equations for the problem are set up. In Chapter 3, the governing equations of the problem are transformed in finite differences form and an iterative procedure is described to solve these equations. A flow chart is also presented to outline the algorithm. Similarly, in Chapter 4, the Finite Element technique has been fully described and the computer flow chart explained. Both the computer programs were run on the computer and computational results obtained for the closed-die cold forging of workpieces of two materials, namely, the electrolytic copper and low carbon steel, and of different slenderness ratio of 0.50, 1.00 and 1.50. Computations were carried out until a total reduction of 20 percent in the heights of the workpieces was attained in all cases. The computed results include: the forging loads, the bulge profiles and the stress and strain distributions throughout the work-pieces. The validity of the computed results has been verified by comparing the computed results of the first stage (that is, almost elastic) with those given by Filon (1902). For checking the computed results over the full range of analysis, experiments on closed-die cold forging of both the materials and for the various slenderness ratios were carried out, as described in Chapter 5. The experimental results include, the forging loads and the bulge profiles. The computed forging loads and the bulge profiles have been compared with those obtained experimentally. The computed results compare very well with those of Filon over the elastic range and with experimental results over the full range of analysis. The computed results have also been compared with those calculated from approximate analytical methods and it has been found that the latter are in significant error as compared to experimental results and those obtained by the present analysis.

In Chapter 6, the computed results, that is, the flow pattern and the distributions of strains, stresses, effective plastic strains and effective stresses have been analysed so as to understand the mechanism of the closed-die forging process, and an effort has been made to understand the pattern of these distributions. Also, the effect of slenderness ratio and strain-hardening coefficient on the forging loads and the bulge profiles have been examined. It has been found that the forging load increases with decrease of slenderness ratio and with increase of strain-hardening coefficient. On the other hand, the bulge (defined as the ratio of the maximum radius and the minimum radius) decreases with decrease in the slenderness ratio and with increase in the strain-hardening coefficient.

Lastly, in Chapter 7, the main conclusions have been summed up and suggestions for future work have been given.

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