STUDIES IN OPEN AND CLOSED DIE FORGING OPERATIONS

BY

RAKESH SAGAR
MECHANICAL ENGINEERING DEPTT

SUBMITTED
IN FULFILMENT OF THE REQUIREMENTS OF THE DEGREE OF
DOCTOR OF PHILOSOPHY

TO THE
INDIAN INSTITUTE OF TECHNOLOGY, DELHI

JUNE, 1980.

C E R T I F I C A T E

This is to certify that the Thesis entitled, "Studies in Open and Closed Die Forging Operations" being submitted by Shri Rakesh sagar 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.

B Lal Juneja 1.91

(B.L.JUNEJA)
Professor
Mechanical Engineering Deptt.,
Indian Institute of Technology
Delhi.

ACKNOWLEDGEMENT

I am grateful to Dr. B.L. Juneja for the inspiration he provided and the constant help he gave at all the stages in the completion of this project.

I am also thankful to Mr. R.N. Mittal who provided all the laboratory facilities. My thanks are due to Dr.G.S.Sekhon, Dr.S.Sengupta who made available the facilities of the Strength of Materials Laboratory for testing of the specimens.

My colleagues, Mr. J.M.Gupta, Dr.N.K.Tewari, Dr. U.R.K.Rao, and Dr. R.S.Parmar extended their whole hearted cooperation and I am grateful to them. I am indebted to Dr. H.B. Mathur for providing the departmental facilities, Dr. Rajneesh Prakash particularly deserves my thanks for his helpful suggestions.

I extend my thanks to the members of the staff of Metrology Laboratory, Mechanical Engineering Department Workshop, Central Workshop, the Production Engineering Laboratory and the Strength of Material Laboratory of IIT Delhi.

I am also thankful to Mr. Harish Bhatia, and Mr.V.P.Gulati for typing and Mr. P.R.Gauba and Mr. Jagdish Chander Nailwal for the making of the drawings.

R. Sagar

RAKESH SAGAR

ABSTRACT

The thesis presents investigations in the open and closed die forging operations. Forging is an age-old process, perhaps, the first process used by human beings to form metal into desired shapes. However, it was only in the last two decades that efforts have been made by many research workers to understand the mode of flow and deformation in forging operations. The inspiration for these researches has partly come from the serious competition to forging process offerred by other processes like casting. There is a need to reduce the material wastage, labour and energy costs in order to make forging process more competitive. Governmental regulations in many countries have put limits on the degree of environmental pollution by noise and smoke. All these factors call for a better understanding of the metal deformation in forging operations so that improvements may be effected and new processes may be evolved.

In most of the forging operations the material flow is quite complex and three dimensional in nature. Process parameters like speed of forging, interface friction and temperature of work piece pose additional difficulties. It is extremely difficult to analyse even the simplest forging process taking all these factors into account. Even if a solution is found, it would be too complicated to be put into practice.

Therefore, approximations in equilibrium equations or boundary conditions or both have been the necessary elements in all the solutions found so far. Even with such approximations, solutions have been possible only for axisymmetric shapes and for plane strain condition. Open die forging of polygonal shapes have been analysed recently. The studies in this thesis extend the horizon of analytical solutions for open die and closed die forging operations. Upperbound technique has been used in all these studies.

The first chapter which is an introduction to the thesis records the historical background of forging operations. It includes the literature survey on the analytical solutions in forging, operations and the available analytical methods. It also gives, in some detail, the upper bound method which has been used in subsequent chapters. This chapter also includes a historical account of the developments made in understanding the nature of friction in metal forming operations. The recent findings, however, justify the assumptions made in the subsequent chapters.

Open die forging of elliptic discs is analysed in the second chapter of the thesis. A kinematically admissible velocity field is determined and analysis for die loads has been made using upper bound technique. A constant frictional stress equal to 'mτ'(where 'm' is the friction factor and

'τ' is the yield strength in shear of the softer material) has been assumed on the interfaces between top and bottom dies. The analysis of a circular disc is a particular case of this (i.e. when the two axes are equal). The velocity field has been determined by minimizing the total energy requirement for each shape of the disc. The ratio of the mean pressure to the yield strength of the material of the disc 'P_m/σ_o' is found for different values of 'a', 'b', 't' and 'm', which are respectively semi-major, semi-minor axes and thickness of the elliptical disc and friction factor with a range of values from zero to one. The values of 'P_m/σ_o' are plotted against 'b/t' for different values of 'm', for a given family of elliptical discs (b/a=0.7). These predictions have been verified by experiments. The value of P_m/σ_o keeps on increasing for similar conditions of lubrication when we go from a circular to an elliptic shape. As the ratio of major axes to minor axes increases the load requirement increases.

In chapter three, the problem of rectangular bar forging with flat tools is analysed. In this the mode of deformation is different with the different values of the ratio of tool width to workpiece thickness(b/t). When the thickness of specimen is large relative to the tool width, the slip line solutions already found adequately describe the mode of deformation, which is nearly of plane strain nature. However, when the workpiece thickness is small, the deformation is three dimensional in nature and the slip line solutions do not fit the situation. An analysis based on upper bound theorem is given for such cases. For obtaining die loads a constant friction stress is assumed on top and bottom interfaces between workpiece and the flat tools. In order to examine the characteristics of the present solution, the values of $\frac{'p_m'}{\sigma_o}$ have been calculated for the different goemetries of the workpiece and tools. The range of values taken cover most of the engineering applications. Bulging is more when the width of the bar is more as compared to its thickness and the bulging tendencey increases with increasing width of the tool and the value of friction factor. These theoretical findings have a close agreement with experimental values.

The fourth chapter of this thesis gives an analysis of open die forging of any irregular four sided disc. Experiments indicate a similar trend. Upper bound technique is used in this analysis with the assumption of constant frictional stress on top and bottom faces. The solution takes into account the bulging of sides during compression as it is experienced in practical forgings.

In chapter five the closed die forging of a hexagonal disc is investigated. Here the die cavity and punch of similar profile are taken and a disc of circular shape is compressed to the hexagonal shape of the die. The metal is completely enclosed in the cavity formed by punch and die. The solution given in this chapter determines the tool forces near the end of the process i.e. when the die corners are nearly full. The kinamatically admissible velocity field chosen for this case satisfies the flow conditions obtained experimentally by observing the deformation of circular grids scribed on the face of the disc. The forging load is due to the power dissipation in deformation, and in overcoming the interface friction on the top and bottom faces, and on vertical side faces. The solution predicts minimum die loads for different sizes of the hexagonal disc which is verified by experiments. The sizes of general purpose hexagonal nuts which give the minimum die loads are slightly smaller than the standard shape for the hexagonal nuts given in ISO R 272 - 1962 and IS 1363-67 for black hexagonal nuts (M 6 to M 39). Thus the solution provides the direction in which both the material and the forming energy can be reduced in the commercial production of nuts and bolts.

In chapter six the velocity field developed in chapter five is utilized for closed die forging of square shapes from circular shapes. The basic assumptions are same as those for the hexagonal shapes. The curves plotted between 'P_m/σ_o' and D/t, show a minimum again indicating an optimum geometry to minimize the energy cost in forging of square shapes. Experiments also indicate that there is an optimum geometry which gives minimum 'P_m/σ_o'.

Chapter seven gives the conclusions. The upper bound technique has been successfully used to predict the metal flow and die loads for different forging operations as given in the earlier chapters. It also includes the scope for future work.

CONTENTS