CHAPTER IX

CONCLUSIONS

Interface friction increases the mean pressures in compression and extrusion. For certain range of geometries the variation of mean pressure with reduction is quasi-oscillatory in nature and the simple algebraic relations between the field parameters applying to frictionless compression and extrusion also extend to these geometries with slipping friction condition at the interfaces. The slipline field solutions for these geometries are of indirect type and the field variables defining the limiting configurations of these solutions depend on the magnitude of the friction parameters at the interfaces. In the case of extrusion, however, the critical angle $\Theta_E$ for the transition eigen fields is found to depend on die friction only and is influenced very little by the container friction.

The approximate techniques like the slab method, upper bound analysis and Green's method yield very accurate estimates of mean pressures for the above problems. Improved upper bounds for plane-strain extrusion are obtained using non-linear minimisation techniques. Since the constraints are eliminated by simple change of variables, complex velocity fields are analysed by this procedure. Further, Green's method, originally formulated
for small die angles is also found to apply to larger die angles with marginal increase in error. For extrusion through wedge-shaped dies, the slipline field solutions for axisymetric extrusion do not differ from the corresponding plane-strain solutions by more than seven percent.

For asymmetric extrusion through square dies, there are a range of geometries for which slipline field solutions cannot be obtained by simple modification of the symmetric fields. Very accurate estimates of mean pressures for these geometries, however, may still be obtained by solution to the above asymmetric fields deduced from the corresponding symmetric fields. But the results so obtained are not exact lower bounds since all stress boundary conditions are not satisfied.

For extrusion through short wedge-shaped dies, slipline field solutions for the coulomb friction situation may be obtained with the help of the matrix method and using non-linear optimisation techniques to determine the field variables without recourse to the usual trial-and-error procedure. But for longer dies and for square dies, the analysis has to be carried out by the usual step-by-step procedure. The time required for constructing the above solutions is considerably reduced by solving the corresponding transcendental equations by Newton-Raphson technique and then generating the co-ordinates on a computer. For square dies, the results calculated in the above manner indicate negligible influence of container friction on mean pressure.
The approximate techniques are also found to yield very accurate estimates of mean pressures for the Coulomb friction situation. However, the upper bound techniques due to Collins (53) and Westwood and Wallace (54) yield identical results in all cases. Very accurate results for the Coulomb friction situation are also obtained from the corresponding mean pressures for the equivalent friction factor $m_e$.

Experimental investigation on symmetric and asymmetric extrusion indicates that introduction of a lubricant significantly reduces friction at the billet-container interface. This is, however, not so for die friction and even under well-lubricated condition the friction factor at the billet-die interface is found to have a high value. Further, the theoretical and experimental mean extrusion pressures do not differ by more than five percent when slipping friction condition is assumed at the die faces for the case of lubricated extrusion.