

THE MECHANICS OF METAL EXTRUSION

W. Johnson & H. Kudo

Manchester University Press, 1962

Contents

INTRODUCTION

PART I

THE ANALYTICAL APPROACH: IDEALISED PROBLEMS

I BASIC PREMISES FOR ANALYSIS 3

II FUNDAMENTALS OF PLANE-STRAIN THEORY WITH SPECIAL

REFERENCE TO SLIP-LINE TECHNIQUES

1. Basic equations for plane-strain problems 7
2. Procedure for solving problems 9

III ANALYSIS OF PLANE-STRAIN STEADY EXTRUSION PROCESS

1. Single-hole symmetric extrusions 12
2. The checking of slip-line solutions 28
3. Effect of undeformed billet length 33
4. Deformation and temperature rise 34
5. Single-hole unsymmetric extrusion 42
6. Stepped die and doubly wedge-shaped die extrusions 50
7. Piercing 54
8. Side extrusion 56
9. Multi-hole extrusion 60
10. Upper bound techniques 69
11. The application of upper-bound techniques 76
12. Other technological theories 79

IV ANALYSIS OF PLANE-STRAIN NON-STEADY EXTRUSION

1. Slip-line solutions 81

2. Upper-bound solutions for simple post-steady extrusion and piercing 86
3. Combined post-steady extrusions 90
4. The first stage of extrusion 96

V ANALYSIS OF AXI-SYMMETRIC PROBLEMS

1. Fundamental equations 97
2. The application of results from plane-strain analysis to steady extrusion 100
3. Upper-bound solutions for steady extrusion and piercing 101
4. Other approximate theories and the effect of undeformed billet length in steady extrusion 107
5. Upper-bound solutions for post-steady extrusions 108
6. Other approximate solutions for non-steady extrusions 111

VI EXPERIMENTAL VERIFICATION OF THEORIES

1. Experimental material and the yield stress 112
2. Lubrication and the coefficient of friction 115
3. The extrusion test 117
4. The experimental analysis of stress and strain in plane-strain problems 122
5. The experimental stress and strain analysis of axi-symmetric problems 124
6. The comparison of theoretical and experimental results on working pressure 135
7. Deformation and defects 140

PART II

APPROACH TO TECHNOLOGICAL PROBLEMS

VII THE EFFECT OF WORK-HARDENING

1. The work-hardening criterion and the stress-strain curve 147
2. The analysis of forming problems for workhardening materials 150
3. The utilization of results from slip-line fields and upper-bound technique investigations 150
4. Alternative theories 155

5. Experimental stress analysis 157

VIII THE EFFECT OF COMPLICATED GEOMETRY

1. The number and shape of holes provided in square dies 159

2. The longitudinal or axial shape of the die 164

3. The effect of the bottom die or ram 169

IX THE EFFECTS OF WORKING SPEED AND TEMPERATURE

1. The effect of speed 173

2. The effect of temperature 175

3. On speed and temperature-dependent problems 177

X SUMMARY

1. Extrusion pressure 180

2. Deformation 182

3. Defects 183

4. The properties of extruded products 189

APPENDICES

I The yield criterion and the stress-plastic strain increment relation 190

II The construction of a slip-line field 191

III The drawing of hodographs 194

IV Determination of stress distribution and extrusion pressure 197

V Prager's stress-plane technique applied to a plane strain extrusion problem in which Coulomb friction is present 200

VI The derivation of upper and lower bounds for the rate of work done by external forces 204

VII To obtain slip-line solutions having a dead metal zone in the case of extrusion through a multi-hole die 208

VIII To obtain a minimum upper bound for extrusion pressure using a rigid triangle velocity field 210

IX Elementary analysis of extrusion through conical 212

REFERENCES 214

AUTHOR INDEX 221

SUBJECT INDEX 223