

DETERMINATION OF THE FLOW CURVE OF NECKING TENSILE
SPECIMEN

NADLENE BT. RAZALI

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

MEI 2010

Specially dedicated to my parents En Razali, Puan Che Nah, family members, Along, Abg KF, Amin, Didi, friends and my love Mohd Irwan.

ACKNOWLEDGEMENT

In the name of Allah, The Most Gracious and The Most Merciful.

First and foremost, I would like to thank with great appreciation and grateful to my thesis supervisor, Professor Ing. Dr Andreas Oechsner for his interest, guidance and consolation during the course for completing this study. His dedicated supervision has made things possible with great experience.

I would like to express appreciation to everlasting friends; Zulia Zura, Nurul Huda, Kak Yati, Kak Eliza, Maysam, Hamid, Idris Rashid, and the rest of fellow classmates and thesis colleagues for their support and motivation.

The great appreciations of all my beloved family; Papa, Mama, Nadia, Amin, Didi, and Irwan. Thank you for your love, endurance, and support.

ABSTRACT

The main objective of this project is to study and to determine the flow curve of necking specimen by using finite element analysis and to validate the approximation formulae of equivalent plastic stress and strain introduced by Bridgman and Davindekov-Spiridonova. This research is done for 3 tensile test specimens with different types of hardening which are ideal plasticity, linear hardening and non linear hardening. In this project, the finite element method is applied for high accurate simulation of tensile tests. The obtained results are discussed in the context of approximation formula and previously known results. Different numbers of element have been carried out in order to study the influence of meshing on the results. From the study, it was found that larger number of elements give stable results, thus, larger number of elements are been choose for simulation. Computer simulation has been done to verify the assumption of the approximation formula and to recognize the possible error. From the results interpretation, it was stated that the error connected with application of the simple formula can be estimated as 10 % in comparison with the numerical simulations, which was considered as the reference solution. The results shows that, the Davidenkov Spiridonova approximation formula give better compared to the Bridgman formula.

ABSTRAK

Objektif kajian yang dijalankan adalah untuk mengkaji dan mendapatkan *flow curve* bagi spesimen ujian tegangan dengan menggunakan kaedah unsur terhingga dan membuat perbandingan antara *von-Mises equivalent stress* dan '*equivalent stress*' formula yang diperkenalkan oleh Bridgman dan Davidenkov-Spiridonova. Kajian ini dijalankan keatas 3 jenis spesimen ujian tegangan yang mempunyai sifat pengerasan yang berbeza iaitu, ideal plastik, pengerasan linear, dan pengerasan tidak linear. Dalam projek ini, kaedah unsur terhingga digunakan untuk mendapatkan keputusan simulasi bagi ujian tegangan yang tepat. Beberapa model yang berbeza jumlah unsur dikaji untuk menentukan pengaruh jumlah unsur kepada hasil keputusan simulasi. Dari kajian, didapati bahawa jumlah unsur yang besar memberikan hasil keputusan yang stabil, dengan demikian, jumlah unsur yang besar ini telah dipilih untuk simulasi ujian tegangan. Dari tafsiran keputusan, didapati bahawa ralat yang diperolehi daripada '*approximation formula*' adalah sebanyak 10% dibandingkan dengan simulasi *numerical*, yang dianggap sebagai penyelesaian rujukan. Keputusan menunjukkan bahawa, *approximation formula* Davidenkov-Spiridonova memberikan keputusan yang lebih baik berbanding dengan *approximation formula* Bridgman.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGES
	TABLE OF CONTENTS	vii
	LIST OF FIGURES	xi
	LIST OF TABLES	xvi
	LIST OF SYMBOLS	xvii
1	INTRODUCTION	1
	1.1 Objective of the Project	2
	1.2 Scopes of the project	3
	1.3 Methodology of the Project	3
	1.4 Thesis Organization	5
2	LITERATURE REVIEW	6
	2.1 Introduction to Necking Study	6
	2.2 Necking in the Tensile Test Formulae of Normalized Axial Stress	8
	2.3 Critical Analysis of Plastic Material Properties	11
	2.4 Influenced of parameter to the equation of Stress and Strain Approximation Formula	18

3	GENERALIZED CONCEPTS OF ELASTIC AND PLASTIC DEFORMATION	20
	3.1 Introduction	20
	3.2 Stress-Strain Relationships	23
	3.2.1 Elastic – Plastic Behaviour	23
	3.3 Material Behaviour	24
	3.3.1 Elastic Perfectly Plastic Model	27
	3.3.2 Elastic-Linear Work-Hardening Model	27
	3.3.3 Elastic-Exponential Hardening Model	28
	3.3.4 Ramberg-Osgood Model	28
	3.4 Yield Criteria	29
	3.4.1 Tresca Yield Criterion	30
	3.4.2 von-Mises Yield Criterion	31
	3.5 Hardening Rule	32
	3.5.1 Isotropic Hardening Rule	34
	3.5.2 Kinematic Hardening Rule	34
4	METHODOLOGY	37
	4.1 Introduction to the Finite Element Analysis	37
	4.2 Finite Element Method	38
	4.3 Finite Element Codes	40
	4.4 Numerical Verification of the Tensile Specimen	41
	4.4.1 Numerical Modeling	42
	4.4.2 Model Description	42
	4.4.3 Meshing the Model	44
	4.4.4 Boundary Condition	47

	4.4.5 Loading the Model	48
	4.4.6 Result Validation and Error Estimation	49
	4.5 Determination of Radius of Curvature	50
	4.5.1 Curvature of Plane Curves	50
	4.5.2 Local expressions	52
5	RESULTS AND DISCUSSIONS	54
	5.1 Results of Meshing Comparison	54
	5.2 Finite Element analysis of tensile test	60
	5.3 Radius of Curvature at Necking Region	62
	5.4 Engineering Analysis on the Stress – Strain Curve	64
	5.4.1 Engineering Stress Strain Curve	65
	5.4.2 True Stress Strain Curve	67
	5.5 Analysis Model for Tensile Test and the Simulation Results	70
	5.5.1 Analysis on the Stress Distribution a the Critical Point After necking	72
	5.5.2 Results of Eq. Stress and Strain along the Critical Necking Nodes at Last Increment	74
	5.5.3 Results Comparison of Distribution of Equivalent Plastic Strain with Approximation Formula.	76
	5.5.4 Assessment on the Equivalent Stress of Simulation Results and Approximation Formula	79
	5.5.5 Analysis on Flow Curve from Finite Element Simulation and the Approximation Formula	82

6	CONCLUSIONS AND FURTHER WORK	86
	REFERENCES	88

LIST OF FIGURES

FIGURE NO	TITLE	PAGE
1.1	Research methodology flowcharts	4
2.1	Neck geometry of a tensile specimen	10
2.2	Initial and final shape of tensile specimen for linear hardening	12
2.3	Distribution of stress component σ_r , σ_z , σ_θ in the minimum section for the last increment (linear hardening)	13
2.4	Comparison of equivalent stresses obtained from FE analysis and the approximation formulae in the minimum section for the last increment for linear hardening	14
2.5	True and equivalent stress as a function of equivalent plastic strain and optical determination of the actual geometry	16
2.6	Equivalent plastic strain as a function of radial coordinate	17
2.7	Triaxiality as a function of radial coordinate	17
2.8	Equivalent Plastic Strain versus the ratio of initial diameter with final diameter	18
2.9	Equivalent Plastic Stress σ_v/σ versus radius of curvature	19

Figure 3.1	Typical stress versus strain diagram with various stages of deformation	20
3.2	Stress-Strain curves	24
3.3	Idealized stress-strain curves	26
3.4	Yield loci for Tresca and von-Mises criteria in a biaxial stress state	31
3.5	Stress-strain curve for uniaxial loading	33
3.6	Isotropic hardening - same shape, different size	34
3.7	Bauschinger effect for uniaxial loading,	35
3.8	Kinematic hardening - same shape, same size	35
4.1	Integration Points for axisymmetric model	40
4.2	Round Cylinder Model for the Tensile test Analysis	41

4.3	Ideal Plasticity	43
4.4	Linear hardening	43
4.5	Non-linear Hardening	44
4.6	Initial meshing	45
4.7	Element with one hanging nodes and transition elements	45
4.8	Fine mesh of axisymmetric model (240 elements)	46
4.9	Description of mesh num of elements	47
4.10	Mechanical boundary conditions for linear hardening.	48
4.11	Mechanical boundary set-up in the MSC Marc	48
4.12	Setting in MSC Marc FE codes for linear hardening	49
4.13	Circle on a curvature	52
4.14	Graph coordinates of y versus x along the necking curvature.	53
5.1	Physical indicator of the problem	54
5.2	Reaction force versus number of elements for ideal plasticity model	55
5.3	Reaction force versus number of elements for linear hardening model	55
5.4	Reaction force versus number of elements for non linear model	56
5.5	y-displacement versus number of elements for ideal plasticity model	56
5.6	y-isplacement versus number of elements for linear hardening model	57
5.7	y-displacement versus number of elements for non linear model	57
5.8	Undeformed shape and deformed shape of tensile specimen for ideal plasticity	60
5.9	Undeformed shape and deformed shape of tensile specimen for non linear hardening	61

5.9	Undeformed shape and deformed shape of tensile specimen for linear hardening	61
5.10	Engineering Stress Strain curve for ideal plasticity	65
5.11	Engineering Stress Strain curve for linear hardening	66
5.12	Engineering Stress Strain curve for non linear hardening	67
5.13	True stress strain curve of tensile specimen	69
5.14	True and equivalent stress as a function of equivalent plastic strain	71
5.15	Distribution of stress component axial stress, radial stress and circumferential stress in the minimum section for the last increment.	73
5.16	Distribution of equivalent stress and equivalent plastic strain in the minimum section for the last increment (ideal plasticity model).	74
5.17	Distribution of equivalent stress and equivalent plastic strain in the minimum section for the last increment (linear hardening model).	75
5.18	Distribution of equivalent stress and equivalent plastic strain in the minimum section for the last increment (non linear hardening model).	76
5.19	Comparison of equivalent plastic strain obtained from FE simulation and approximation formula at the critical necking region for the last increment (ideal plasticity model)	77
5.20	Comparison of equivalent plastic strain obtained from FE simulation and approximation formula at the critical necking region for the last increment (linear hardening model)	78

5.21	Comparison of equivalent plastic strain obtained from FE simulation and approximation formula at the critical necking region for the last increment (non linear hardening model)	79
5.22	Comparison of equivalent stresses obtained from finite element analysis and approximation formula in the minimum section for the last increment of ideal plasticity model.	80
5.23	Comparison of equivalent stresses obtained from finite element analysis and approximation formula in the minimum section for the last increment of linear hardening model.	81
5.24	Comparison of equivalent stresses obtained from finite element analysis and approximation formula in the minimum section for the last increment of non linear hardening model.	82
5.25	Exact and reconstructed flow curves for ideal plasticity.	83
5.26	Exact and reconstructed flow curves for linear hardening.	83
5.27	Exact and reconstructed flow curves for non linear hardening.	84
5.28	Comparison of error estimation between two approximation formula, Bridgman and Davidenkov-Spiridonova.	84

LIST OF TABLES

TABLE NO	TITLE	PAGE
4.1	Material properties of Specimen	40
4.2	Load applied	49
4.3	Coordinate of x and y along the necking curvature for non linear hardening model (Inc = 600)	53
5.1	Results of Meshing Comparison	59
5.2	Radius of curvature for Ideal Plasticity Model	63
5.3	Radius of curvature for Linear Hardening Model	63
5.4	Radius of curvature for Linear Hardening Model	64

LIST OF SYMBOLS

SYMBOL	DESCRIPTION
ρ	curvature of the longitudinal stress trajectory
a	radius at necking area
R	Radius of curvature
$\bar{\sigma}_z$	Equivalent stress
F	Force
A	Area
d	Diameter
ε_N	natural strain
ε_c	engineering strain
σ	true stress
E	Young's Modulus
$d\varepsilon$	increment of strain
$d\varepsilon_e$	elastic strain increment
$d\varepsilon_p$	plastic strain increment
$d\sigma$	stress increment
E_t	tangent modulus
ν	Poisson's ratio
ε_p	plastic strain
σ_Y	yield stress
k	characteristic constants

N	characteristic constants
σ_{v_M}	von-Mises equivalent stress
σ_{T_r}	Tresca equivalent stress
σ_θ	circumferential stress
σ_r	radial stress
τ_{max}	maximum shear

CHAPTER 1

INTRODUCTION

The tensile test is one of the important standard engineering procedures to characterize some important elastic and plastic variables which are related to the mechanical behavior of materials. The mechanical properties that can be determined from the tensile test include yield stress, ultimate tensile stress, Young's modulus and Poisson's ratio of the material. The engineering stress-strain curve does not give a true indication of the deformation characteristics of a metal because it is based entirely on the original dimensions of the specimen, and these dimensions change continuously during the test. Furthermore, due to the non uniform stress and strain distributions existing at the neck for high levels of axial deformation, it has been long recognized that significant changes in the geometric configuration of the specimen have to be consider in order to properly describe the material response during the whole deformation process up to the fracture stage. Although in many engineering applications the design of structural parts is restricted to the elastic response of the material involved, the knowledge of their behavior beyond the elastic limit is relevant since plastics effect usually large deformations take place in many manufacturing procedures such as metal forming. Other important applications of elastoplastic models for metal are crashworthiness, impact problems, inelastic buckling of thin-walled structures, and

superplastic forming. Analytically the derived formula serves in practical use to evaluate the complex stress and strain state in the necking region of tensile test. Among the others, the formula proposed by Bridgman and Davindenkov-Spirinova are well-known and considered in this research. This research project will analyze the flow curve behavior of ductile material by using the FEM to validate the approximation formula which is introduced by Bridgman and Davindenkov-Spirinova

1.1 Objective of the Project

The main objective of this research project is to find the flow curve of a necking specimen which is subjected tensile load. Most of the current research is focused on the material behavior under tensile load which finally breaks in a ductile or brittle manner. The procedure of the current research includes analyzing the equivalent stress and strain distribution e.g by applying the von Mises equivalent stress, the surface metallography investigation, the critical analysis of plastic material properties and carrying the tensile test to compare the result with analytical and numerical solution. In this research project, the flow curve of tensile specimens will be analyzed by using the finite element method.

The major steps of this research project for both simple plate and round cylinder specimen are define as below:

- To investigate the influence of parameters (Radius of curvature and ratio of deformation $\frac{\sigma_v}{\sigma}$) on the equivalent stress and strain for the tensile test.
- To validate the approximation formulae of equivalent plastic stress and strain introduced by Bridgman and Davindekov-Spiridonova with finite element method analysis and estimate the involved error.
- Study the necking of the material
- Analyze stress distribution after necking

- Analyze the stress and strain state in all points of the material

1.2 Scopes of the project

In this work, the main objective is to investigate the flow curve after necking of a tensile specimen. After necking a multiaxial stress state exists which finally results in the failure of the specimen. The project will be carried out by using Marc Mentat (Finite Element Analysis software). The FEA results will be used to validate some approximation formulae e.g (Bridgman 1964). A round cylinder specimen will be analyzed in this research project.

1.3 Methodology of the Project

The goals are mainly achieved by finite element method analysis which are then compared the results with some approximation formulae and estimate the error. This research covers the study of equivalent stress and strain distribution. The numerical method of analysis is carried out by using the finite element method Marc Mentat (MSC) software. The research methodology flowcharts systematically highlighting the major work of the study are shown in Figure 1.1.

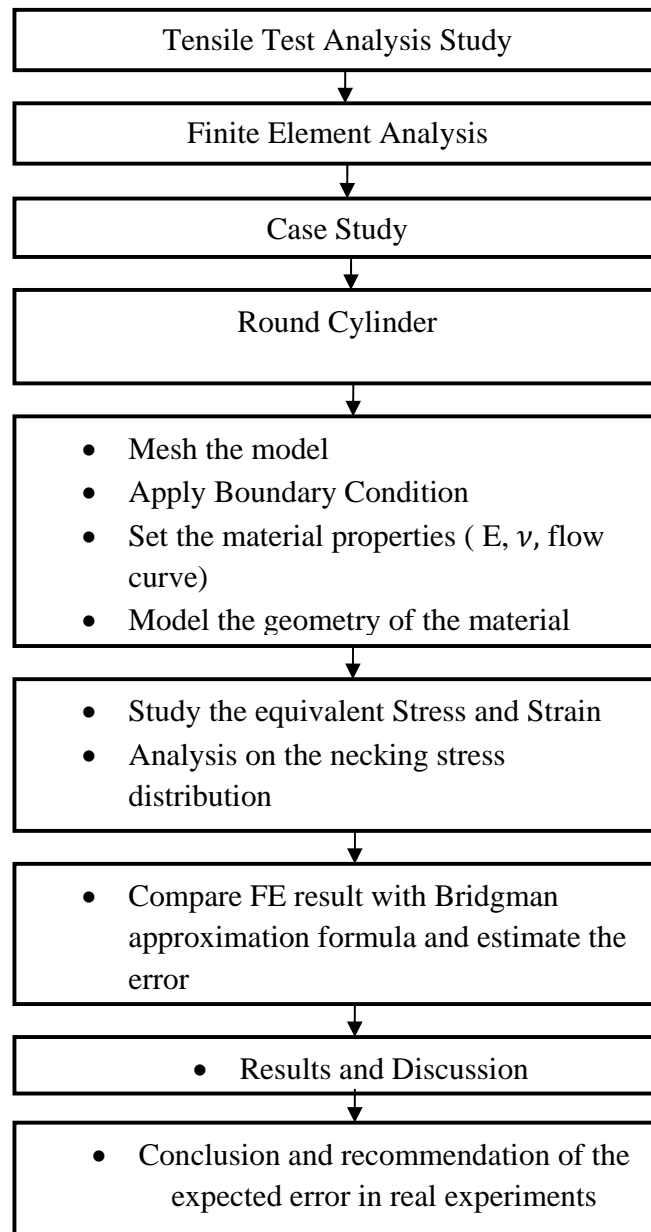


Figure 1.1: Research methodology flowcharts

1.4 Thesis Organization

The thesis consists of six chapters. The current chapter discusses the problem definition, justification for carrying out the research, objective, scopes and the research methodology of the project.

Chapter 2 reviews some of the previous researches on the tensile analysis of equivalent plastic stress and strain. A brief description and discussion of the basic fundamentals of stress-strain relationship are introduced in Chapter 3. Besides that, the fundamental concepts and theories that are related to the research are reviewed in this chapter.

Numerical investigations using finite element models are given in Chapter 4. The problems are solved by using Marc Mentat MSC finite element software. Chapter 5 will be discussing about the results of equivalent stress and strain evaluate by using some of approximation formulae and the results will be compare with the finite element analysis. The results and discussion in details will be state in this chapter.

The conclusions are stated in Chapter 6 together with the summary of the findings of the research and suggestions for other areas of additional research.