

SUPERVISOR DECLARATION

“I hereby declare that I have read this thesis and in my opinion this report is
Sufficient in terms of scope and quality for the award of the degree of
Bachelor of Mechanical Engineering (Design and Innovation)”

Signature :

Supervisor : Dr. Hady Effendy

Date :

**DESIGN AND SIMULATION
OF THREE DIMENSIONAL BENDING MACHINE**

NG SZE LING

**This thesis is fulfillment of the requirement for the award of Bachelor Degree in
Mechanical Engineering (Design and Innovation)**

**Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka**

June 2013

DECLARATION

“I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged.”

Signature :

Author : NG SZE LING

Date :

This project is dedicated to my lovely parents who have always giving me moral support during the time I developing the design and finishing the project. They have never left my side but constantly giving me encouragement which give me tenacity to done my project. Furthermore, I also dedicate this work to my siblings as they providing some recommendation to me especially teaching me that even the largest task can be accomplished if it is done in step by step. Thanks to them for their love and the strength that they gave to me in achieving my goal. Last but not least, thanks God give me His wisdom to arrange all the time and gather all the information to done the project.

ACKNOWLEDGEMENTS

This project would not be possible to carry on if without the supporters. Hence I would like to acknowledge all the people that were involve directly and indirectly while completion of the project.

First of all, I would like to thanks sincerely to my supervisor, Dr. Hady Efendy for spending his precious time in guiding me with his expertise and giving his moral support. This countless time that he spent in reflecting, encouraging, and advising patiently throughout the entire process help me a lot in finishing this project. I have learned many from him and gained my confidence from the project.

Furthermore, I would like to acknowledge and thanks to En. Wan Farid for his willingness to provide feedback and information that regarding to the project. These are very important to me in completing the research successfully. Furthermore, special thanks to the staff members especially the technicians in FASA B, FKM for allowing me to conduct my research and providing any assistance requested.

Besides that, I would like to thanks all friends for their understanding and encouragement when I facing problem. They are willing to spend the time to cheer me up and sharing ideas. Although I cannot list them all here but they are always in my mind, I appreciate it.

Last but not least, I would like to thanks God accompany me all the way.

ABSTRACT

In sheet metal forming, a simple shape profile is formed between tools or dies to obtain a complex geometry with the properties and desired tolerances. Nowadays, three-dimensional U-bending process is widely applied in many manufacturing industries, that it could be fabricated with a low production cost. However, after three-dimensional U-bending process, it usually produces spring back problem, little scrap, high percentage of deflection and change of the characteristic of the sheet metal. As a result, three-dimensional U-bending machines is designed and develop with a minimum amount of errors. Furthermore, Finite Element Method (FEM) with commercial software CATIA V5, computer based simulation is an absolute necessity to check the errors and the effects of the process parameters. A study of the principle variables of the sheet metal forming processes and their interactions is essential for this project. These variables include the flow behavior and formability of the formed sheet material under processing conditions, material, coatings and geometry of the die, friction and lubrication, the mechanics of the deformation, stresses, strains and forces, and last are characteristics of the specimen forming presses and tooling.

TABLE OF CONTENT

ACKNOWLEDGEMENTS	v
ABSTRACT	vi
1.0. INTRODUCTION	1
1.1. OBJECTIVES	2
1.2. SCOPES	2
1.3. PROBLEM STATEMENT	2
1.4. FLOW CHART	3
2.0. LITERATURE REVIEW	4
2.1. THE MECHANICS OF U-BEND DEFORMATION	4
2.2. BEND ALLOWANCES	7
2.3. STRESS AND STRAIN CONSIDERATION	8
2.4. SPRING BACK	12
2.4.1. Factors of Spring Back	13
2.5. BENDING MACHINES	14
2.6. MATERIAL	17
2.6.1. Material for Three-dimensional U-bending Machine	17
2.6.2. Material for Specimen Test	17
2.7. SIMULATION	20
2.7.1. Finite Element Method Simulation (CATIA V5)	20
2.7.2. Key Benefits Include In CATIA V5	20
2.7.3. Result of Finite Element Method Simulation	21

3.0. METHODOLOGY	23
3.1. GATHER INFORMATION.....	24
3.2. IDENTIFY PROBLEM.....	24
3.3. DESIGN.....	24
3.4. CONCEPTUAL DESIGN.....	25
3.5. DETAIL DESIGN.....	27
3.6. EVALUATION DESIGN.....	27
3.6.1. Objective Tree.....	28
3.6.2. House of Quality.....	29
3.7. ANALYSIS DATA FROM EXPERIMENTAL RESULT.....	31
3.8. ANALYSIS BY FEM SIMULATION.....	31
3.9. COMPARISON BETWEEN EXPERIMENTAL RESULTS AND ANALYTICAL RESULT.....	31
3.10. FEM SIMULATION.....	32
4.0. RESULT	34
4.1. PART DESIGN DRAWING.....	34
4.1.1. Specimen test.....	34
4.1.2. Jig Male.....	35
4.1.3. Jig Female.....	36
4.1.4. Sliding Guide.....	37
4.1.5. M8*25 Steel Hexagon Socket Head Cap Screw.....	37
4.1.6. Steel Plain Washer for 8*18.8.....	38
4.1.7. Assembly View.....	38
4.1.8. Exploded View.....	40
4.2. RESULT OF CLASH CHECKING ON CATIA V5.....	41
4.3. PART DESIGN FOR EXPERIMENT.....	42
4.3.1. Jig Male.....	42

4.3.2.	Jig Female, Sliding Guide, M8*25 Screw and Steel Plain Washer	43
4.3.3.	Assembly View	43
4.3.4.	Exploded View	44
4.4.	EXPERIMENT	46
4.4.1.	Experimental Processes.....	47
4.5.	EXPERIMENTAL RESULTS	48
4.5.1.	Summary of Experimental Results	48
4.5.2.	Analysis of Experimental Result.....	50
4.6.	ANALYTICAL RESULTS	52
4.6.1.	Simulation by CATIA V5	52
4.6.2.	Analysis by CATIA V5.....	53
4.6.3.	Analytical Result.....	54
5.0.	DISCUSSION	60
5.1.	COMPARISON	60
5.1.1.	Reasons of the Stress Increasing	62
5.1.2.	Reasons of the Stress Decreasing.....	64
5.1.3.	Reasons of the Errors	64
6.0.	CONCLUSION.....	65
6.1.	RECOMMENDATION.....	66
	REFERENCES.....	67
	APPENDIXES	70
	Gantt Charts	74
	Drafting	75

LIST OF TABLES

Table 1: Bending Machines	14
Table 2: Properties of Stainless Steel 316L	19
Table 3: Morphological Chart.....	26
Table 4: House of Quality, HOQ	30
Table 5: Summary of Experimental Result.....	48
Table 6: Analytical Result.....	59
Table 7: Table of Experimental Results and Analytical Result	61
Table 8: Gantt chart for PSM 1	74
Table 9: Gantt chart for PSM 2	75

LIST OF FIGURES

Figure 1: Sheet metal bending profile	1
Figure 2: Flow chart of the project.....	3
Figure 3: Typical stressed U-bending.	6
Figure 4: Example of typical specimen dimensions.	7
Figure 5: Stress profile	9
Figure 6: True stress-strain relationship for U-bending.....	10
Figure 7: Single stage stressing and the method.	11
Figure 8: Two stage stressing and method	12
Figure 9: Spring back	13
Figure 10: Air bending.....	14
Figure 11: Bottoming	14
Figure 12: Coining	15
Figure 13: Three-point Bending.....	15
Figure 14: Folding.....	15
Figure 15: Wiping	16
Figure 16: Rotary Bending.....	16
Figure 17: Elastomer Bending	16
Figure 18: Stress distribution analysis and spring back features by FEM simulation	22
Figure 19: Comparison on experiment and FEM simulation analysis.	22
Figure 20: Flow Chart of Methodology	23
Figure 21: Objective tree 1.....	28
Figure 22: Objective tree 2.....	29
Figure 23: Specimen's Material Properties for CATIA V5	33
Figure 24: Stainless Steel 316L Properties	33
Figure 25: Stainless Steel 316L for specimen test by CATIA V5	34
Figure 26: Jig Male by CATIA V5	35
Figure 27: Jig Male by CATIA V5	35

Figure 28: Jig Female by CATIA V5.....	36
Figure 29: Jig Female by CATIA V5.....	36
Figure 30: Sliding Guide by CATIA V5.....	37
Figure 31: M8 * 25 Steel Hexagon Socket Head Cap Screw by CATIA V5	37
Figure 32: Steel Plain Washer for 8*18.8 by CATIA V5	38
Figure 33: Assembly View by CATIA V5	38
Figure 34: Assembly Open View by CATIA V5.....	39
Figure 35: Assembly Close View by CATIA V5	39
Figure 36: Exploded View by CATIA V5	40
Figure 37: Exploded View by CATIA V5	40
Figure 38: Result of Clash Checking by CATIA V5.....	41
Figure 39: Jig Male	42
Figure 40: Jig Female, sliding guide, M8*25 screw and Steel Plain Washer.....	43
Figure 41: Assembly View.....	44
Figure 42: Exploded View	45
Figure 43: U-Bending Experiment Process.....	46
Figure 44: U-bending process	47
Figure 45: U-bending process is end.....	47
Figure 46: Graph of Average Experimental Force versus Thickness Reduction.....	50
Figure 47: Graph of Average Experimental Stress versus Thickness Reduction	51
Figure 48: Graph of Average Experimental Force and Stress versus Thickness Reduction	51
Figure 49: Simulation.....	52
Figure 50: Simulation Process for Open View	52
Figure 51: Simulation Process for Close View	53
Figure 52: Deformed Mesh	54
Figure 53: Analytical Stress for Original Thickness, 2mm	54
Figure 54: Analytical Stress for 1.8mm	55
Figure 55: Analytical Stress for 1.6mm	55
Figure 56: Analytical Stress for 1.55mm	56
Figure 57: Analytical Stress for 1.4mm	56
Figure 58: Analytical Stress for 1.2mm	57
Figure 59: Analytical Stress for 1.0mm	57
Figure 60: Analytical Stress for 0.8mm	58

Figure 61: Analytical Stress for 0.6mm	58
Figure 62: Graph of Analytical Stress versus Thickness Reduction.....	59
Figure 63: Graph of Compressive Stress and force Applied versus Specimen's Thickness Reduction	61
Figure 64: Graph of Stress versus Strain.....	62
Figure 65: 2.0mm Microstructure by 500 Magnifying Glass	63
Figure 66: 1.55mm Microstructure by 500 Magnifying Glass	63
Figure 67: Graph of Hardness versus Thickness Reduction	63
Figure 68: 2.0mm Microstructure by 500 Magnifying Glass	64
Figure 69: Stress - Strain Graph for 0.6mm.....	70
Figure 70: Stress-Strain Graph for 0.8mm.....	70
Figure 71: Stress-Strain Graph for 1.0mm.....	71
Figure 72: Stress-Strain Graph for 1.2mm.....	71
Figure 73: Stress-Strain Graph for 1.4mm.....	71
Figure 74: Stress-Strain Graph for 1.55mm.....	72
Figure 75: Stress-Strain Graph for 1.6mm.....	72
Figure 76: Stress-Strain Graph for 1.8mm.....	73
Figure 77: Stress-Strain Graph for 2.0mm.....	73

LIST OF SYMBOLS

FEM	= Finite Element Method
HOQ	= House of Quality
n/a	= Not Applicable
%RT	= Percentage of Reduction in Thickness
avg.	= Average
max.	= Maximum

CHAPTER 1

INTRODUCTION

1.0. INTRODUCTION

Bending is a metal forming process which a force is applied to a sheet metal to forming an angled or sheet profile. A bending operation causes deformation along one axis. Bending dies is to classify according to their design. To perform a single bending operation, dies are designed which may include L, V, U or Z bends or other profiles. (Vukota Boljanovic, 2004) The parameters of U-bend profiles are shown in **Figure 1:** (CustomPartNe, 2009)

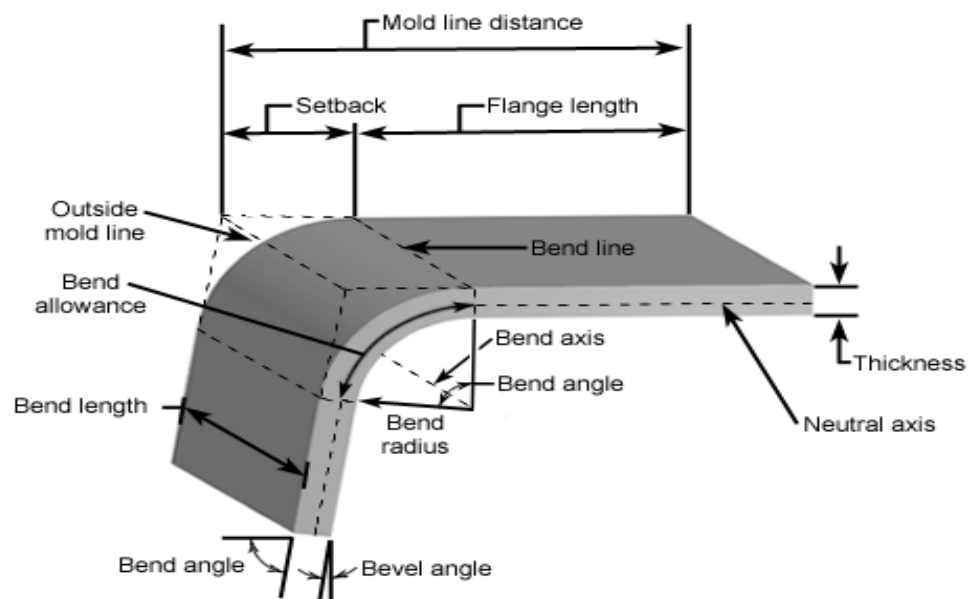


Figure 1: Sheet metal bending profile

(Source: CustomPartNet, 2009)

Simulation is very significant in a U-bending design process. Simulation enables to analyze the design in factors of quality, performance, characteristics, and properties of the U-bending before development process. In simulation, finite element method, FEM is used to investigate the precision of U-bending process. The FEM simulation enable to make a clearly identified of the stress distribute in specimen and the parameters changed after visual U-bending process.

1.1. OBJECTIVES

- To develop and design the three dimensional U-bending machine.
- To simulate U-bending process of Stainless Steel 316L by software CATIA V5.
- To analyze the result from experiment to commercial software CATIA V5.
- To understand the characteristics of the Stainless steel 316L after U-bending process.

1.2. SCOPES

Study on the development of three-dimensional U-bending machine. It is design for manufacture of Stainless Steel 316L U-bending specimen test. For the design of the machine, simulation of U-bending process and structural analysis are carried out. The analysis is carried out by FEM simulation using the commercial software CATIA V5.

1.3. PROBLEM STATEMENT

There is imperfection on the current three-dimensional U-bending machines, which leads to high percentage of deflection, spring back problem, and characteristic changed from theoretical result. Therefore, a design of three-dimensional U-bending machine is significant to minimize the errors. After that, a study on the simulation of three-dimensional U-bending process is to be conducted. It is conduct by Finite Element Method, FEM simulation by using the commercial software CATIA V5.

1.4. FLOW CHART

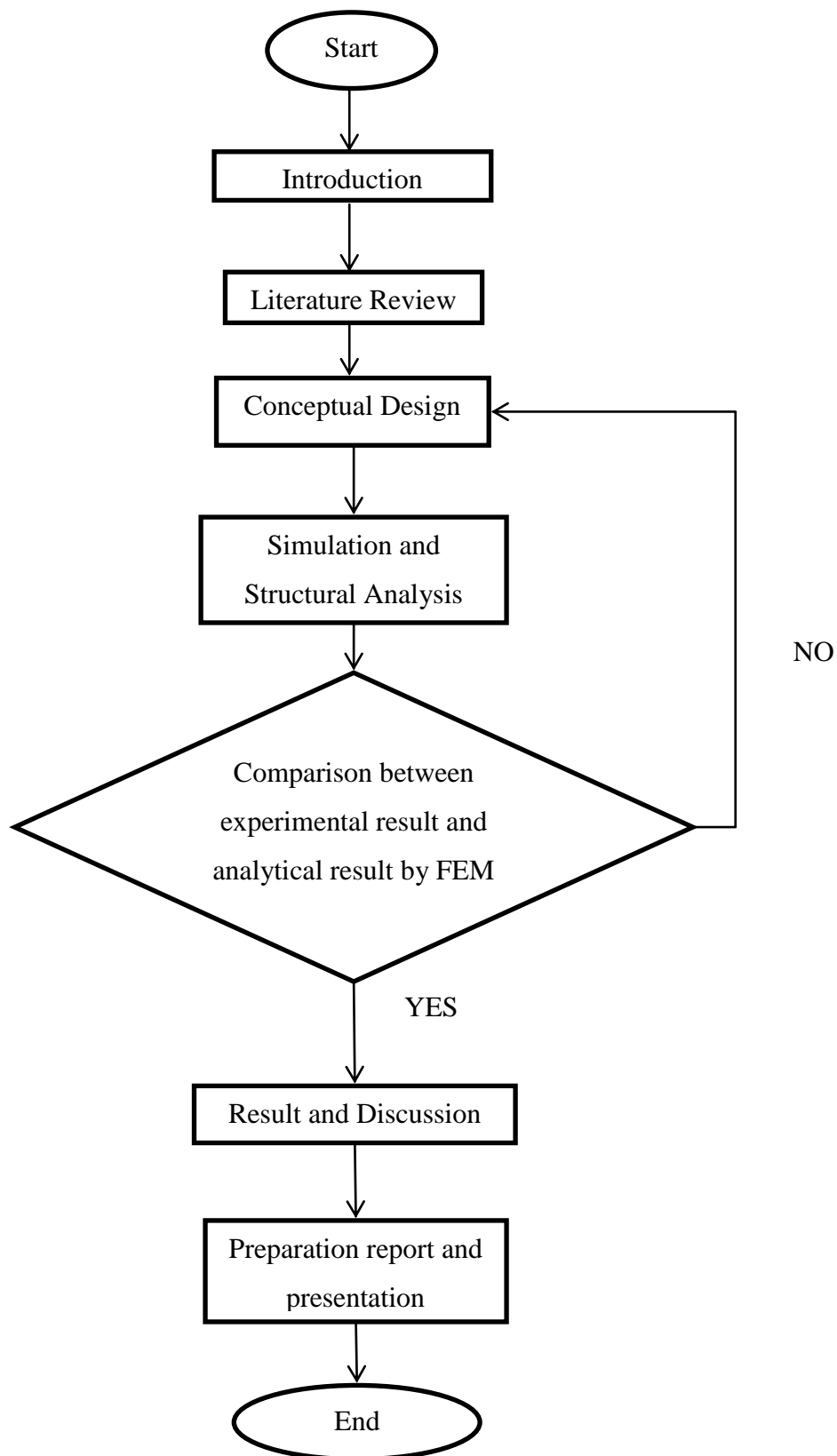


Figure 2: Flow chart of the project

CHAPTER 2

LITERATURE REVIEW

2.0. LITERATURE REVIEW

This chapter will discuss about the theory and information that related to the project. The information is gathered through journals, books, articles, online documents, and some website. This chapter is significant to done the project, this is because the ideas, concepts and some theory can easily generate and get from the information that have gathered. From the information, research and the experience that have done by others, it is very benefit and save the time to do the research and design for three-dimensional U-bending machine.

2.1. THE MECHANICS OF U-BEND DEFORMATION

The mechanics of deformation are significant to consider in designing a bending system. For example,

- Bendability assessment.
(Determining minimum bend radius without fracture).
- Prediction of bending forces.

- Control of the dimensional, spring back, tolerances, residual stresses, wrinkling, and splitting.
- Sheet metal properties
(Thickness, properties, and surface finish)
- Equipment / machine used
(Control and capacity)
- Tools
(Material and coating)
- Deformation work zone
(Strain, stress, and force)
- Product
(Dimensions and quality)
- Environment
(Handling and safety) (Taylan Altan *et al.* 2012)

Normally U-bending process is containing high elastic and plastic strain. However, sometime for a very thin sheet or very small diameter wire it is possible produce only elastic strain only for U-bend process. Furthermore, U-bending provides one of the most severe tests available for smooth which are as opposed to notched or precracked, stress-corrosion test specimens. The specimens that contain single stressed are not suitable for study on the effects of different applied stresses on stress corrosion and mirror effect on cracking. The advantages of the U-bending process are simple and economical to make and use. **Figure 3** is shows the typical U-bending configurations with several different of maintaining the applied stress. (ASTM, 2003)

The parameters are very important to determine the failure of the U-bending process to a very small radius. There are depending on the sheet thickness, ductility of the material, bending angle, and loading conditions. U-bending severity is expressed as the R/t ratio, where R is the U-bend radius, and t is the thickness of specimen.

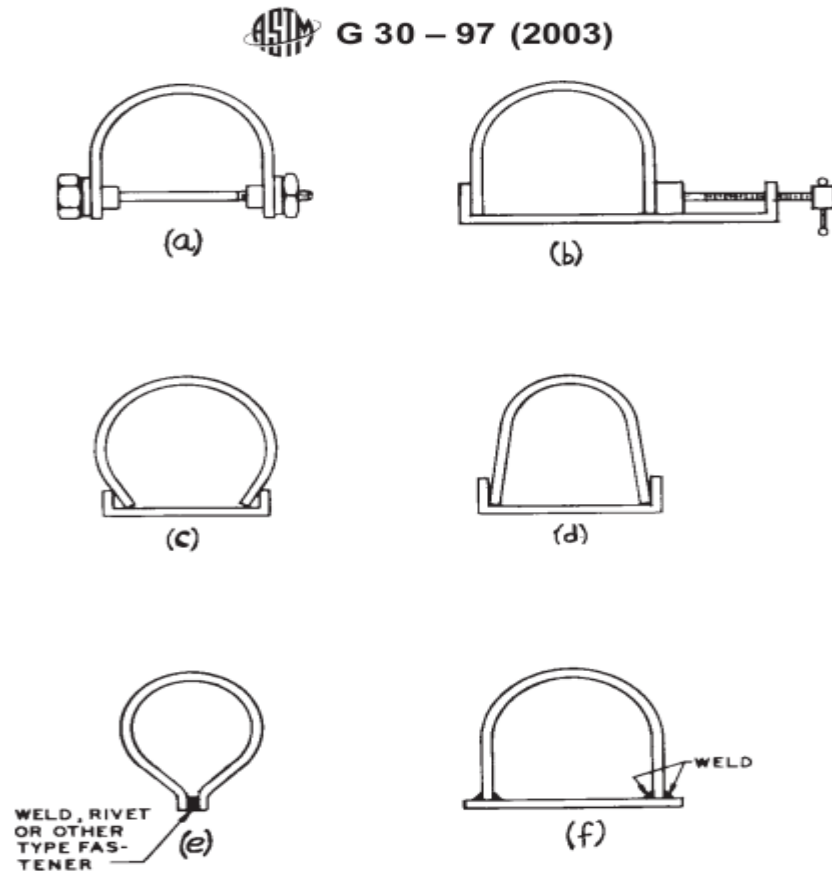


Figure 3: Typical stressed U-bending
(Source: ASTM, 2003)

U-bending processes that get high rates of crack propagation usually is the material that having high strength. Due to the highly stressed condition in a U-bending process, these pieces may give high velocity on specimen and this is very dangerous. For the specimen dimensions of U-bending, **Figure 4** shows examples of typical test specimen and lists. From the examples, some dimension combinations that haven been used successfully to test a wide range of materials.

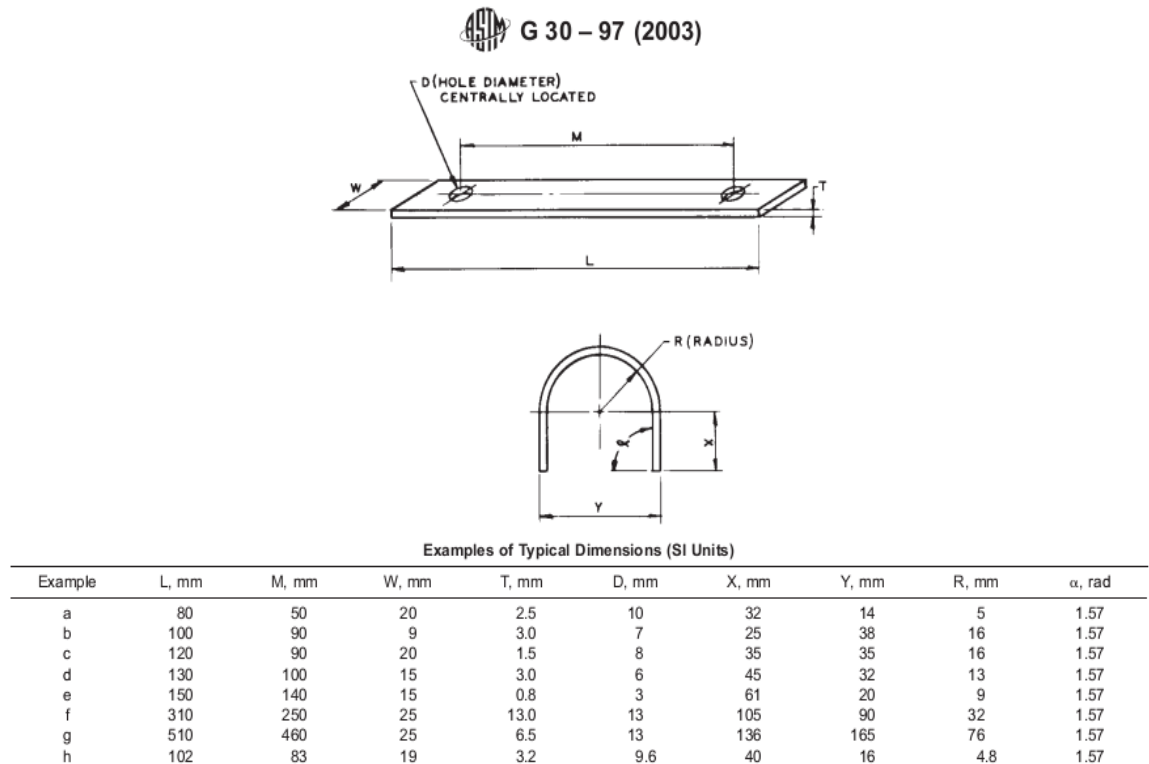


Figure 4: Example of typical specimen dimensions

(Source: ASTM, 2003)

2.2. BEND ALLOWANCES

According to Kutz (2002), dimension is changed after bending, increased in length. It is significant to take consideration the length tolerance for the processes of product and die designing. From **Figure 1**, bent length can be calculated by the equation of

$$B = \frac{A}{360} \times 2\pi (R_i + Kt) \quad (2.1)$$

Where,

B = bend allowance (along neutral axis)

A = bend angle

R_i = Inner bend radius

t = specimen thickness

K = 0.33 when R_i is less than 2t

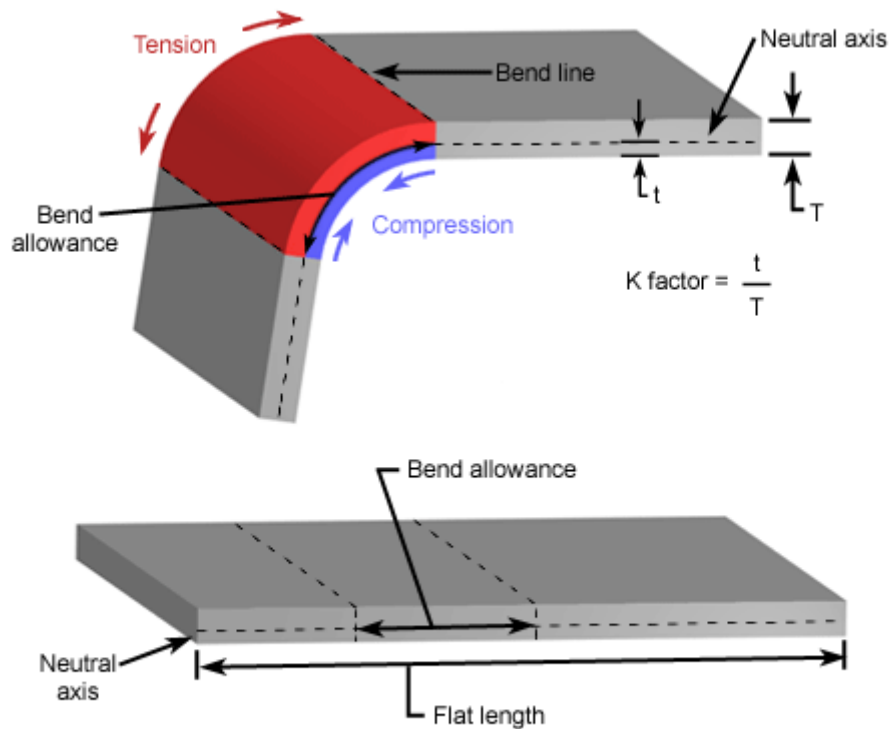
= 0.50 when R_i is more than 2t

2.3. STRESS AND STRAIN CONSIDERATION

The principal interest of stress in the U-bending process is circumferential. Due to there is a stress gradient, stress become non-uniform and produce a stress gradient. Outer surface will undergo tension force, and the inner surface will undergo compression. Hence, length in neutral axis is remains constant, there have no any change of length. However, there having a neutral axis between the inner and outer surface. In a neutral axis, it is undergo free of stress, which no tension or compression force. **Figure 5** is shows the stress profile on a bending specimen. K-factor is to calculate the location of the neutral axis. K-factor is depending on the material, bending operation, bend angle and others. K-factor cannot greater than 0.50 and normally is greater than 0.25.

$$\text{K-factor} = \frac{t}{T} \quad (2.2)$$

Stress gradient will go thought the thickness to a maximum compression on the inner surface from a maximum tension on the outer surface. The gradient stress is from the ends of the specimen, zero to a maximum at the neutral axis. Stress gradient will vary across the width of the specimen bending. (Consultants, 2007)



Copyright © 2009 CustomPartNet

Figure 5: Stress profile
(Source: CustomPartNet, 2009)

For a U-bending specimen is stressed, outer surface of the material may undergo plastic deformation of the true stress-strain curve. **Figure 6(a)** is shown. **Figure 6(b)** to **6(e)** are show several stress-strain relationships that may exist in the outer surface of the U-bending process. Method of the stressing is influence the actual relationship.

The total strain, ϵ on the surface of the bend can be approximated to the equation of

$$\epsilon = \frac{T}{2} R, \text{ when } T \ll R \quad (2.3)$$

where T = specimen thickness, and R = radius of the bend curvature.

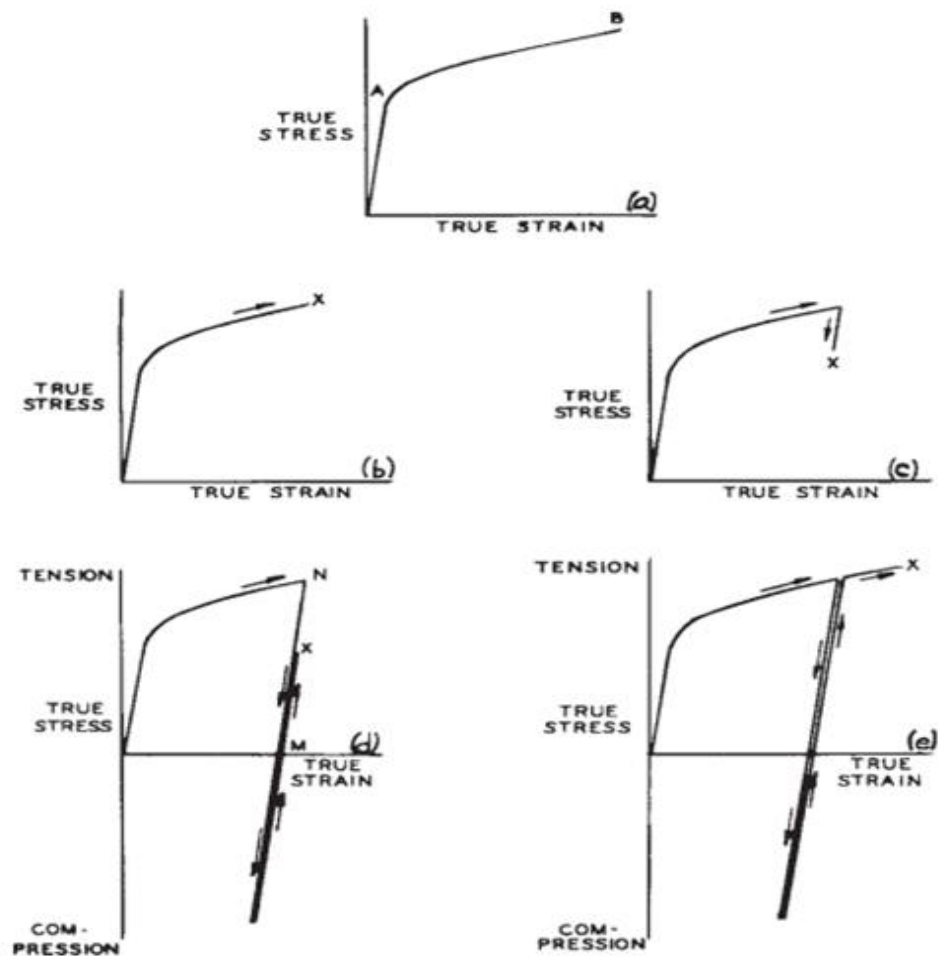


Figure 6: True stress-strain relationship for U-bending

(Source: ASTM, 2009)

There are two methods of stressing on specimen. There are single stage stressing and two stage stressing. Single stage stressing is accomplished by bending of the specimen followed by relaxation of the tensile elastic strain. Single stage stressing is also defined as point X in **Figure 6(b)** and **Figure 6(c)**. Furthermore, for a single stage stressing, there is a slight spring back at the end of the stressing sequence for some elastic strain relaxation has occurred. The examples for methods of single stage stressing are shown in **Figure 7**. **Figure 7(a)** shows the tension testing machine. It is more suitable for large thickness or high strength material or both. **Figure 7(c)** shows the U-bending method which is more suitable for thin or low strength material or both. However, it may lead to a greater lack of control of the bend radius, spring back problem. (ASTM, 2003)

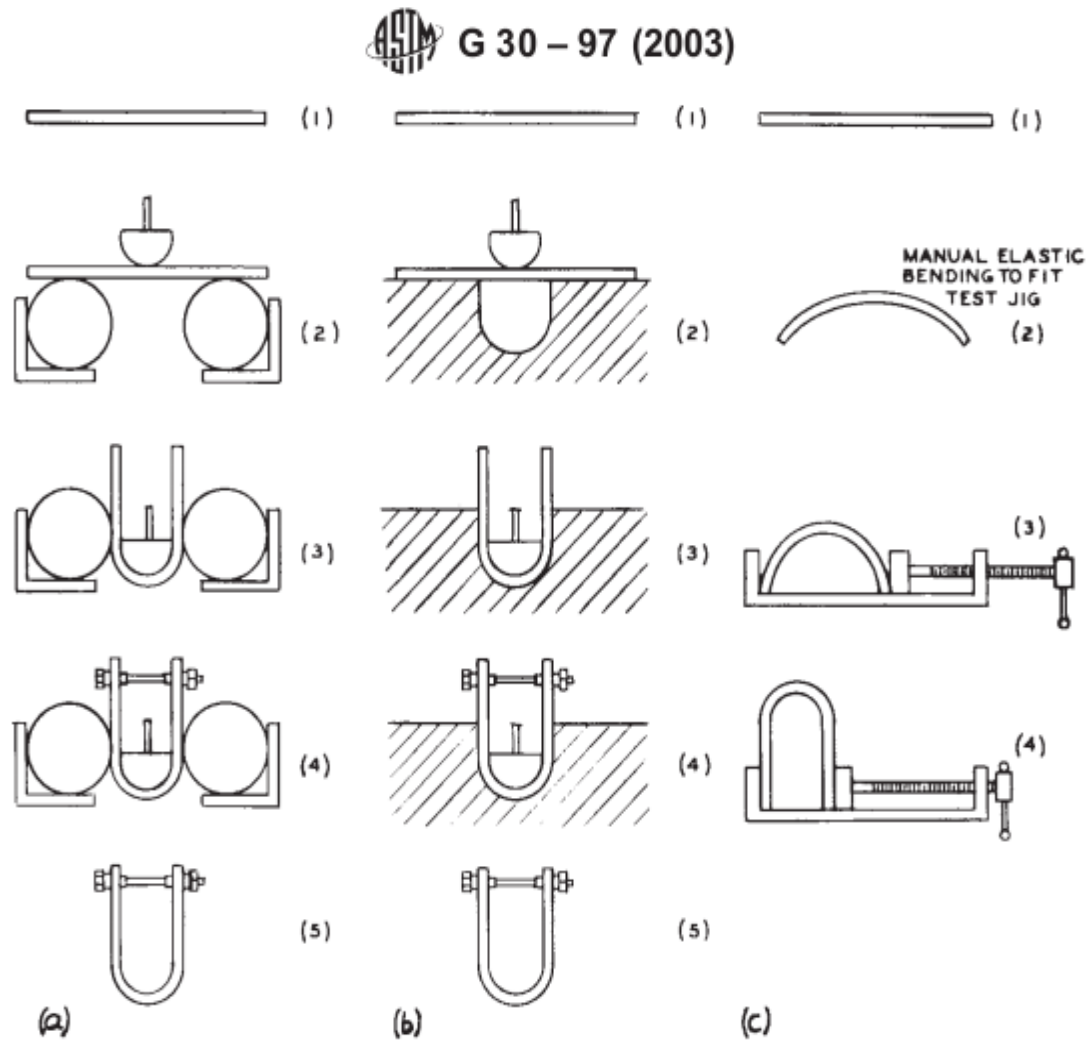


Figure 7: Single stage stressing and the methods

(Source: ASTM, 2003)

For the two-stage stressing methods are shown in **Figure 8**. This method involves first forming the approximate U-shape, then allowing the elastic strain to relax completely before the second stage of applying the test stress. For the second stage stress is applied, it may result in the percentage of tensile elastic strain during U-bending process as shown in **Figure 6(d)**. It also involves additional plastic strain as shown in **Figure 6(e)**. **Figure 8(b)** is the first stage stress to perform the approximate U-shape. **Figure 8(c)** and **Figure 7(d)** are to maintain the stress and avoid the spring back problem of the U-bending legs. (ASTM, 2003)