EXPERIMENTAL AND ANALYTICAL EVALUATION OF BENDING FOR STAINLESS STEEL

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Report submitted in partial fulfilment of the requirements
for the award of Bachelor of Mechanical Engineering

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JUNE 2012

ABSTRACT

Analytical calculation is one of the methods in predicting the spring-back angle after bending process. Precise predictions of spring-back angle after the bending process are the key to the design of the bending die, bending tool, and to produce the accuracy part geometry. This thesis purpose is to determine the reliability of analytical method in V-bending analysis of stainless steel by comparing the results with experimental results and the experimental measurements of Özgür (2008). The effects of significant parameters including sheet thickness and sheet anisotropy on spring-back in V-bending analysis also have been studies. The mechanical properties that provided from tensile test experiment have been used in the analytical calculation in solving the spring-back equation. Two different equations from previous studies have been used to determine the spring-back angle. In the V-bending experiment, two different test procedures (bottoming and air V-bending process) were used. The experimental results have been used to evaluate the analytical results. The results of this project shown the spring-back values for analytical calculation are generally is not in agreement with the experimental value but the graph trends obtained in this study are generally in agreement with experimental graph patterns. The graph patterns are also in agreement with the past study by other researcher (Özgür, 2008). Increasing the sheet thickness resulted increase in the spring-back angle. The orientation angle and anisotropy value *R* will influence the spring-back. In general, the spring-back angle is increase if the orientation angle is increase. Therefore, the 0 degree orientation angle is a suitable condition in V-bending processes because the spring-back value is smallest compared to other orientation angles. The percentage error is very high because there are some errors occur during the tensile specimen preparation, tensile test experiment and V-bending test experiment. The accuracy and precision of machine in collecting and determined the data is a factors as the higher percentage error. It is conclude that the analytical method is not suitable in sheet metal bending analysis of stainless steel. This is because, combination of various material types and process parameters make the exact prediction of spring-back difficult.

Key words: Stainless steel; V-bending; Spring-back

ABSTRAK

Pengiraan analitikal adalah salah satu kaedah di dalam menentukan bukaan sudut selepas proses membengkok. Ketepatan di dalam menentukan bukaan sudut selepas proses membengkok adalah kunci kepada proses meraka bentuk acuan dan untuk menghasilkan ketepatan bahagian geometri. Tujuan tesis ini adalah untuk menilai ketepatan kaedah pengiraan analitikal dengan membandingkan keputusannya dengan keputusan eksperimen dan juga keputusan eksperimen yang telah dibuat oleh Özgür (2008). Kesan-kesan parameter penting seperti kesan ketebalan kepingan dan kesan anisotropi terhadap bukaan sudut di dalam analisis pembengkokan-V juga dikaji. Sifat-sifat mekanikal keluli tahan karat yang diperolehi dari eksperimen ujian ketegangan telah digunakan untuk menyelesaikan pengiraan bukaan sudut. Dua persamaan berbeza daripada kajian lalu telah digunakan untuk menganggar bukaan sudut. Di dalam eksperimen pembengkokan-V, dua prosedur yang berbeza (bottoming and air V-bending) telah digunakan. Keputusan eksperimen telah digunakan untuk menilai ketepatan keputusan pengiraan analitikal. Keputusan projek telah menunjukan bahawa nilai bukaan sudut bagi pengiraan analitikal secara umumnya adalah tidak sama dengan nilai keputusan eksperimen tetapi tren graf yang diperolehi di dalam kajian ini adalah sama dengan tren graf eksperimen. Tren graf juga sama dengan tren graf yang diperolehi dari kajian terdahulu (Özgür, 2008). Bukaaan sudut akan meningkat sekiranya ketebalan kepingan meningkat. Sudut orentasi dan nilai anisptropi *R* akan memberi kesan kepada bukaan sudut. Secara umumnya, lebih besar sudut orintasi akan menyebabkan bukaan sudut menjadi lebih besar. Oleh itu, orientasi sudut 0 darjah adalah yang paling sesuai untuk proses pembengkokan-V kerana nilai bukaan sudutnya adalah yang paling minima berbanding orientasi sudut lain. Peratus ralat sangat tinggi kerana terdapat beberapa ralat berlaku semasa proses penyedian specimen ujian ketegangan, eksperimen ujian ketegangan dan eksperimen pembengkokan-V. Ketidak tepatan mesin dalam pengumpulan data adalah factor menyebabkan peratus ralat tinggi. Kesimpulannya, kaedah pengiraan analitikal adalah tidak sesuai digunakan untuk analisis pembengkokan-V bagi keluli tahan karat. Ini kerana, terdapat pelbagai jenis bahan dan parameter proses membuatkan anggaran bukaan sudut menjadi sukar.

Kata kunci: Keluli tahan karat; Pembengkokan-V; Bukaan sudut

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$\Delta\theta/\theta$	Spring back ratio
n	Strain hardening exponent
R	Normal anisotropic value
v	Poisson’s ratio
E	Young’s modulus
t	Sheet thickness
ρ	Neutral axis
$\Delta\theta$	Spring back angle
I	Inertia moment of cross-section per unit width
$M(\alpha)$	Bending moment along the bending surface
R_n	Neutral layer radius of the sheet
K	Ultimate tensile strength
w	Die gap
t	Sheet thickness
ΔK	Spring back curvature
M	Bending moment
L	Inertia moment of cross-section

LIST OF ABBREVIATIONS

AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Material
TRIP	Transformation Induced Plasticity
CNC	Computer Numerical Control
UTS	Ultimate Tensile Strength
DKL	Daw-Kwei Leu
DFPH	Dongye Fei and Peter Hodgson

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

This chapter provides a brief overview of the entire project. It consists project background, problem statement, objectives, scopes and flow chart of the project.

1.2 PROJECT BACKGROUND

Materials testing are often the first step in the manufacturing process to measure the quality of the material. If the material that uses into the product is defective, then the product will be defective. Quality cannot be put in after the fact. In forming materials, understanding the materials properties can help to better predict the manufacturing outcome and result. Study the effect of spring-back in bending process can reduce cost in the die design and die making.

Some measured properties that must be considered when designing a new product include tensile strength, yield strength and Young’s Modulus of Elasticity. Another important property is ductility, which is the ability for plastic deformation in tension or shear. Ductility controls the amount a material can be cold formed, which is the process used when forming automobile bodies or wire products. Two commonly used indices of ductility are total elongation and reduction of area. For suppliers, the mechanical properties are an important measure of product quality, and buyers often require certification of the values.

In this project, tensile test have been conducted to determine the mechanical properties. The mechanical properties that provided from tensile test have been used in the analytical method in solving the spring-back equation. Then, experimental of the effects of significant parameters including sheet thickness and sheet anisotropy on spring-back or spring-go in V-bending processes of stainless steel have been conducted. The results of the experiments have been used to evaluate the reliability of analytical method in sheet metal bending analysis of stainless steel.

1.3 PROBLEM STATEMENT

Spring-back is a very significant problem in sheet metal forming industry, especially in sheet bending process. The dimension precision is a major concern in bending process, due to the considerable elastic recovery during unloading which leads to spring-back. In a certain conditions, it is also possible for the final bend angle to be smaller than the original angle that normally called as a spring-go. The amount of spring-back or spring-go is depended by various process parameters, such as tool shape and dimension, contact friction condition, material properties, sheet anisotropy and sheet thickness. The accuracy of the methods such as analytical calculation and finite element analysis in predicting the spring-back value are also a major concern in V-bending analysis.

1.4 PROJECT OBJECTIVES

The objectives of this project are:

i. To determine the spring-back angle in sheet metal bending of stainless steel.
ii. To determine the mechanical properties of stainless steel from tensile test experiment.
iii. To determine the effects of significant parameters including sheet thickness and sheet anisotropy on spring-back in V-bending analysis.
iv. To determine the reliability of analytical method in sheet metal bending analysis of stainless steel.

1.5 PROJECT SCOPES

The scopes of the project are limited to:

i. Study the basic understanding of spring-back behaviour from the past researchers.
ii. Conduct experiment for V-bending using press brake bending machine and measure the spring-back angle.
iii. Perform an analytical method to determine the spring-back angle of V-bending.
iv. Compare the experimental result with analytical method.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will discuss about the standard material and it properties used for this project. Then, the theory of tensile and bending test will be study base on the past researched. Lastly, the processes to predict the spring-back angle in experimental and analytical method are study in this chapter.

2.2 MATERIAL

Selecting material for engineering application is important to make sure that material is suitable for the products. In this study, the stainless steel AISI 304 sheet metal has been selected as a material to perform the experimental and analysis for bending test.

2.2.1 Stainless Steel AISI 304

Stainless steel sheet metals have a wide range of application in industry. This material is commonly used for reactor components, consumer products and medical devices. Changes made in the composition of stainless steel to obtain the required mechanical and chemical properties according to the fields used influence their cold shaping. High tensile strength, resistance to corrosion, low thermal conductivity and ductility that stainless steels possess and presence of a great amount of chrome nickel and some amount of molybdenum, strength enhancing elements, are the primary factors that complicate cold shaping compared to other materials. Majority of these products around us are formed by means of a bending apparatus, die or machine, and it is essential that these metal parts be within the required dimensions and tolerance limits. The required dimensions and tolerance limits obtain are depends on the amount of spring back of the material bent. (Özgür, 2008)

2.2.2 Stainless Steel Properties

According to Z. Tourki (2005), the material used in the investigation was the 316 and 304L stainless steel obtained from thin sheet (1 mm) of austenitic stainless steel. The chemical composition of the materials is given in Table 2.1. The mechanical basic characteristics, which are the hardening exponents and their anisotropy coefficients, are described in Table 2.2. The treatment results in a recrystallized structure with an average grain dimension of 100 μm for the 304 steel and 150 nm for the 316 steel.

Table 2.1: Chemical composition of the two studied nuances: AISI304 and AISI 316

Nuances	C	Si	Mn	Cr	Ni	Mo	N	Cu	Fe
AISI 304	0.05	0.41	1.14	18.04	9	0.193	0.04	0.348	Balance
AISI 316	0.06	0.055	1.85	16.8	12.3	2.59	0.03	0.057	Balance

Source: Z. Tourki (2005)

Table 2.2: Mechanical characteristic of the two studied nuances: AISI 304 and AISI 316

Nuances	$R_{p0.2}$ (MPa)	R_M (MPa)	A (%)	r	n	ϕ Grains
AISI 304	315	690	58	0.94	$n_1 = 0.14$ ($\varepsilon \leq 10\%$) $n_2 = 0.43$ ($\varepsilon > 10\%$)	100 μm
AISI 316	320	625	58	0.94	0.41	150 μm

Source: Z. Tourki (2005)

According to Óscar Martín (2010), the chemical composition and the mechanical properties of the AISI 304 sheets, respectively, are shown in Table 2.3 and Table 2.4. The sheet thickness is 0.8 mm. The metallographic characterization of parental metal, which is obtained by using electrolytic etching with oxalic acid, is according to ASTM A262-91 Practice A.

Table 2.3: Chemical composition of the AISI 304 sheets (wt %)

C	**Cr**	**Ni**	**Si**	**Mn**	**Mo**	**Al**	**Co**
0.08	18.03	8.74	0.426	1.153	0.36	0.003	0.17
Cu	**Nb**	**Ti**	**V**	**W**	**Fe**	**P**	**S**
0.39	0.02	0.004	0.05	0.03	70.48	0.019	0.002

Source: Óscar Martín (2010)

Table 2.4: Mechanical properties of the AISI 304 ASSI sheets

Yield strength (MPa)	**Tensile strength (MPa)**	**Total elongation (%)**	**Micro hardness (HV, 100 g)**
290	675	70	162

Source: Óscar Martín (2010)

2.3 TENSILE TEST

According to J.R. Davis (2004), tensile test is one of the most common methods used for evaluating materials. The tensile test is accomplished by gripping the opposite ends of the specimen within the load frame of a test machine. Tensile force is applied by the machine, resulting in the gradual elongation and eventual fracture of the test specimen. During the tensile test process, force-extension data, a quantitative measure on how the test specimen deforms under the applied tensile force, usually monitored and recorded. When the method is conducted properly, the result gain by tensile test force-extension data that can quantify several important mechanical properties of a material such as elastic deformation properties (Young’s modulus and Poisson’s ratio), yield strength, ultimate tensile strength, ductile properties (elongation and reduction in area) and strain-hardening characteristics.

2.3.1 Specimen

According to the ASTM standard, the specimen of the tensile test can be divided into three types where it is plate type specimen, sheet type specimen and round type specimen. In this project, the test specimen is sheet metal type. Normally, the specimen has enlarged ends or shoulders for gripping. The cross-sectional area of the gage section is reduced relative to that of the remainder of the specimen so that deformation and failure will be localized in this region. The shoulders of the test specimen can be manufactured in various ways to mate to various grips in the testing machine. Both ends of the specimens should have sufficient length and a surface condition such that they are firmly gripped during testing. (J.R. Davis, 2004)

The standard sheet type test specimen according to ASTM standard is shown in Figure 2.1. This specimen is used for testing metallic materials in the form of sheet, plate, flat wire, strip, band and hoop ranging in nominal thickness from 0.13 to 19.0 mm. The detail dimension and specification of the tensile test specimen is shown in the Figure 2.1 and Table 2.5.

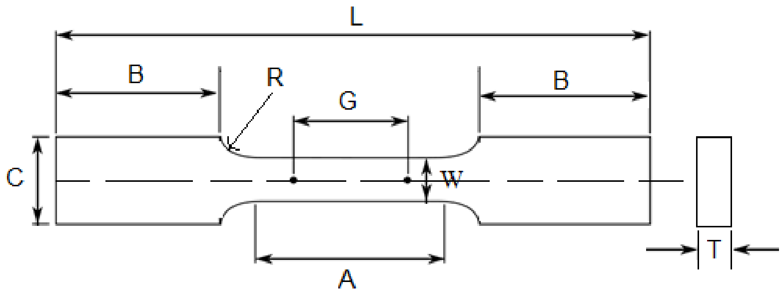


Figure 2.1: Examples of rectangular (flat) tensile test specimen

Source: Annual Book of ASTM Standards (2003)

Table 2.5: Dimension and specification of the tensile test specimen ASTM E8

	Plate type (1.5 in. wide) mm	**Sheet type (0.5 in. wide) mm**	**Sub-size specimen (0.25 in. wide) mm**
Gage length	200 ± 0.25	50.0 ± 0.10	25.0 ± 0.08
Width	40 + 3 - 6	12.5 ± 0.25	6.25 ± 0.05
Thickness	Thickness of Material		
Fillet radius (min.)	13	13	6
Overall length (min.)	450	200	100
Length of reduced section (min.)	225	60	32
Length of grip section (min.)	75	50	32
Width of grip section (approx.)	50	20	10

Source: Annual Book of ASTM Standards (2003)

2.3.2 General Procedures of Tensile Test

After testing specimen has been prepared, the tensile test will be conducted for test the physical behaviour of the sample. The test specimen will be placed properly at the grips and if required, extensometers or strain gauge or any other strain measuring devices can be used with the test specimen for measurement and recording of extension data. To ensure that the test will run at the proper testing speed and temperature, the testing should be monitored all the time. The test is started by applying the force to the test specimen. (J.R. Davis, 2004)

2.4 BENDING TEST

Bending is a common metal forming process used in sheet metal forming to fabricate curve and angle shaped products of various sizes, such as parts of automobiles, ships and aircraft. Furthermore, this process also used in making the various consumer products, such as kitchenware and sanitary products. The bending process concept is based on engineering science and has a wide variety of applications. Furthermore, bending also features in many sheet metal forming processes, such as the deep drawing and stamping processes shown in Figure 2.2.

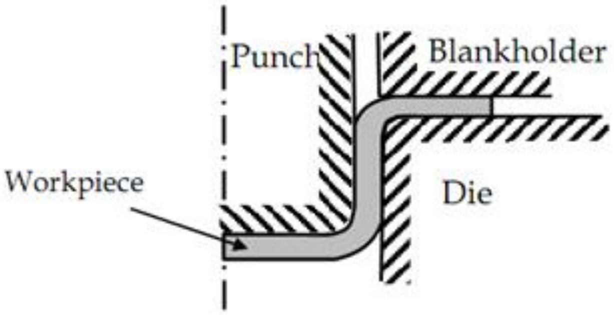
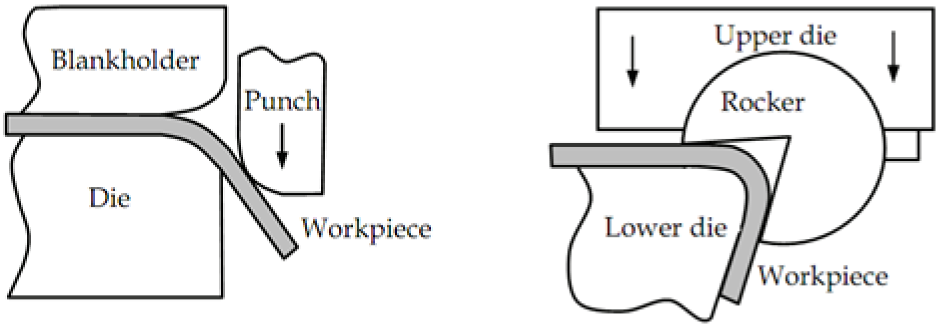


Figure 2.2: Bending in deep drawing process

Source: Sutasn Thipprakmas (2010)

The bending process is divided into two group types which are bending by using a linear die motion and bending by using a rotating die motion. Bending by using a linear die motion is the tool moves linearly to bend the work piece. For example, the wiping die bending and U-bending processes, shown in Figure 2.3 (a). Bending by using a rotating die motion is a tool moves in rotations to bend the work piece, as shown in Figure 2.3 (b). The advantages of rotary bending are elimination of the use of a blank holder, less bending force requirement, and a final bending angle greater than 90 degree.



(a) (b)

Figure 2.3: Classification of bending process (a) Linear die motion (b) Rotating die motion

Source: Sutasn Thipprakmas (2010)

Bending is a manufacturing process where a force, corresponding to a given punch displacement, acts on the work piece. The work piece is initially bent in an elastic region. When the process continues, the work piece is deformed by plastic deformation and changing its shape. The bending load increases until the elastic limit of the material is exceeded in the bending process. Sheet metal can be formed when the material state enters the plastic deformation region. In addition, the stress generated in the work piece is greater than the yield strength but lower than the ultimate tensile strength of the material. The work piece initially deforms where the bending moment is the greatest. For example, the process of permanent deformation starts directly underneath the punch in the case of the V-bending process. During the bending process, the outer surface of the work piece generates the greatest stretch, which then expands inward toward the neutral plane. Similarly, the inner surface of the work piece generates the greatest compression, which also then expands inward toward the neutral plane. These distributions of the stresses are shown in Figure 2.4.

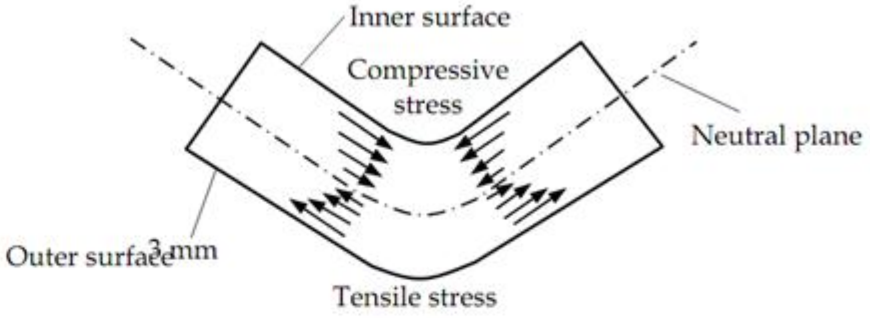


Figure 2.4: Stress distribution in the V-die bending process

Source: Sutasn Thipprakmas (2010)

2.4.1 Principle of V-die Bending Process

The V-bending process can be defined as a bending of a V-shaped part in a single die. The principle of the V-die bending process is shown in Figure 2.5. The work piece is bent between a V-shaped die and punch. The force acting on the punch causes punch displacement and make the work piece is bent. The work piece is initially bent as an elastic deformation. The process continued downward motion by the punch, and when the stresses exceed the elastic limit, the plastic deformation sets in. This plastic deformation start occurs on the outer and inner surfaces directly underneath the punch. The greatest tensile stress is occurred on the outer surface and the greatest compressive stress is occurred on the inner surface. These stresses decreasingly expand inward toward the work piece. In addition, crack formation usually occurs on the outer surface and a wrinkle usually occurs on the inner surface. The initial bending stage is known as Air bending. Air bending is a process that starts from the moment the punch establishes contact with the work piece and is completed either when the legs of the work piece become tangential to the faces of the die or when the smallest internal radius of the work piece becomes smaller than the radius of the punch. As the process continues, after completion of air bending, the bending is focused on the three points of the punch and the two faces of the die. The contact points between the work piece and die are shifted toward the centreline of the die, and the legs of the work piece try to close around the punch. As the punch proceeds further, the legs of the work piece establish contact with the punch, and it is pressed to open up again until the bend angle approaches the die angle (Schuler, 1998). The clearance between the punch and the die in V-bending is commonly dependent of the work piece thickness. The usual thickness of the work piece in the V-bending process ranges from approximately 0.5 to 25 mm.

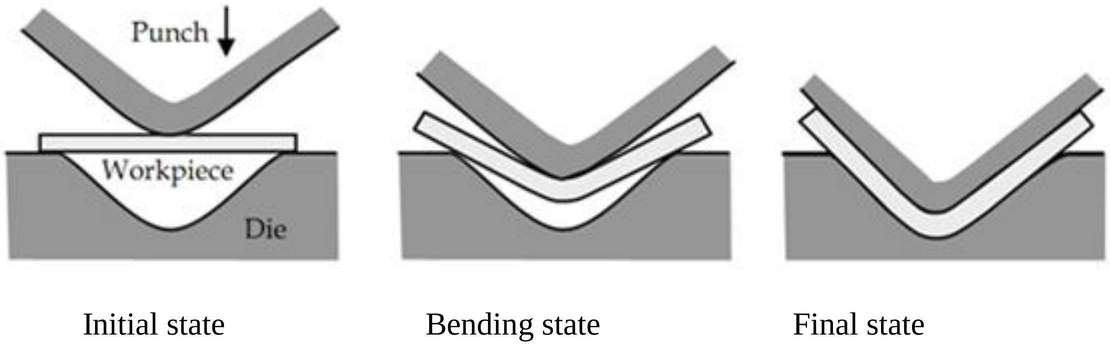


Figure 2.5: Principle of V-bending process

Source: Sutasn Thipprakmas (2010)

2.4.2 Spring-back Phenomenon

The material is generally divided into two zones according to the plastic deformation theory where it is the elastic and the plastic zones. The elastic property tries to maintain the material in the initial shape, whereas the plastic property tries to retain the material in the deformed shape. In the sheet metal bending process, the bending load increases until the elastic limit of the material is exceeded and then the material state enters the plastic deformation zone. The outer surface of the material generates the tensile stress, which propagates inward toward the neutral plane. Vice versa, the inner surface of the material generates the compressive stress and it propagates inward toward the neutral plane. Because of the stress distributions, this phenomenon causes the formation of a small elastic band around the neutral plane, as shown in Figure 2.6. As the bending force is removed at the end of the bending stroke, the inner surface–generated compressive stress tries to enlarge the work piece and the outer surface–generated tensile stress tries to shrink. In contrast, the elastic band remains in the bent parts trying to maintain its original shape, resulting in a partial recovery toward its