IDENTIFICATION OF MIXED HARDENING PARAMETERS FOR ALUMINIUM SHEET BY CYCLIC LOADING TOOL

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ABSTRACT

This project is about identifying mixed hardening parameters of aluminium alloy AA 1100 by cyclic loading tool. The identified parameters are useful as input data in sheet metal forming simulation. It helps to improve the performance of the simulation to solve forming problem such as springback. The cyclic loading tools are fabricated to perform bending-unbending. Software Mastercam is used to generate G-code for advance machining on the fabrication process. The newly developed tool is installed on the tensile test machine for cyclic bending-unbending experiment. The experimental data acquired are converted into stress- strain data which are further analysis by using Matlab for parameters identification. The mixed hardening parameters for various thicknesses are obtained at the end of the project. R-square error are used to justify the accuracy of the parameters. The mixed hardening equation which is the combination of isotropic hardening law and kinematic hardening rule are fitting to the experimental data very well. Improvements in the newly developed tools are suggested to reduce friction and hence obtain better results.

ABSTRAK

Projek ini membentangkan pengenalan campuran pengerasan parameter aloi aluminium AA 1100 dengan menggunakan alat kitaran muatan. Parameter yang dikenal pasti akan digunakan untuk mengkaji lembaran logam yang dibentuk dan mengenal pasti masalah kerosakan seperti membidas. Alat kitaran muatan dihasilkan untuk menjalankan kajian pembengkokkan dan sebaliknya. Software MASTERCAM menghasilkan G-kod untuk proses fabrikasi. Alat kitaran muatan yang dihasilkan akan dipasang pada mesin ujian tegangan untuk menjalankan kajian pembengkokkan dan sebaliknya. Daripada keputusan yang diperoleh, analisis tekanan dan terikan digunakan untuk menjalankan analisis tersebut dengan MATLAB. Pendekatan curve fitting digunakan untuk menjalankan analisis tersebut. Pengerasan campuran parameter untuk pelbagai ketebalan diperolehi pada akhir kajian. Ralat R-persegi digunakan untuk mewajarkan ketepatan parameter. Persamaan pengerasan campuran merupakan gabungan teori isotropi pengerasan dan kinematik pengerasan. Melalui persamaan tersebut, area plastik di aloi aluminium dapat diramal secara tepat. Penambahbaikan pada alat kitaran muatan yang disyorkan adalah mengurangkan geseran demi mendapatkan keputusan yang lebih tepat.

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LIST OF SYMBOLS

σ^o	Yield stress
Q	Material parameter (maximum change in size of elastic range)
b	Material parameter (rate at which the elastic range develops)
C	Material parameter (hardening modulus)
γ	Material parameter (rate at which kinematic hardening modulus decrase as plastic deformation develops)
ε	Strain
ρ	Radius of curvature
M	Bending moment
I	Moment of inertia

LIST OF ABBREVIATIONS

CNC	Computer Numerical Control
LS	Least Squares
RSM	Response Surface Methodology
EDM	Electrical Discharge Machining

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Sheet metal specimen experiences cyclic loading condition in many sheet metal forming processes. The hardening behavior of materials under such conditions is more complicate than monotonic loading. The yield stress of materials in reverse loading is usually lower and the subsequent hardening rate is higher than in the case of continuous loading under Bauschinger effect, Therefore the conventional isotropic hardening model is no longer an adequate approximation.

For some materials under reverse loading, consideration of the Bauschinger effect is required for a realistic tress distribution, which is in turn essential for the prediction of springback under bending-unbending conditions (Geng, 2000; Geng and Wagoner, 2000). In the past decades, many engineers has been investigated the methods to describe the smooth transient behavior during the reverse loading. Currently the combined isotropic-kinematic hardening model has been widely used in the sheet forming field, since it can depict the Bauschinger effect and the smooth elastic-plastic transition as well as the isotropic hardening effect.

1.2 PROBLEM STATEMENT

Aluminium alloy sheets are widely used for the automotive applications due to its improvement of the fuel efficiency with lighter weight. Therefore some efforts are being put in order to utilize aluminium alloy sheets. However, the major technical problem that needs to overcome for this application is the large springback of aluminum sheets (Lee et al., 2004).

The magnitude of the springback is roughly proportional to the ratio between the residual stress and Young's modulus. Residual stresses of material after forming stage are the main factor to determine the magnitude of springback. Prediction of residual stresses are depends on the material modeling during the forming simulation. In order to make up the material model, the hardening law is considered as one of the most important factors for accurate stress distribution prediction (Eggertsen, 2006).

1.3 OBJECTIVES

The aims of this study are to:

- Fabricate the new cyclic loading tools.
- Identify the reliable mixed hardening parameters for aluminium by using a new develop cyclic loading tool.

1.4 SCOPE OF STUDY

The scopes of the project are highlighted as follows:

- Literature review of the existing experimental method, mixed hardening rule, and optimization method.
- Sketch the design by using SolidWork according to its dimension.
- Fabricate a new cyclic loading tool by using milling machine and CNC machine to improve prediction about the mixed hardening parameter
- Generate G codes by using Mastercam software for the CNC machine.
- Conduct the experiment by using tensile test machine and record the experimental data.
- Analyze the experimental data to obtain reliable mixed hardening parameter by using optimization methods.

CHAPTER 2

LITERATURE REVIEWS

2.1 INTRODUCTION

Many theories have been proposed to explain about the phenomenon of springback for bending process. Although the literature widely covered of such theories, this review will focus on four major themes throughout the literature review. These themes are: bending, mixed hardening rules, springback, and optimization.

2.2 BENDING PROCESS

The one of the oldest manufacturing processes known to mankind is sheet metal forming (Fries-Knoblach, 1999). Sheet metal forming processes are processes that transform the geometry of the sheet metal by applying a force to a piece of sheet metal without remove any material. The applied force must beyond its yield strength of material to causing the material plastically deform. Therefore the sheet metal can be bent into any various shapes.

Bending can be considered as a basic variant of sheet metal forming. Bending is a metal forming process in which a certain amount of force stresses a piece of sheet metal to causing the metal bend into the desired angle and shape. A combination of several different bending operations can create a complex part of the product. A bend can be characterized several different parameters shown in the image below. Figure 2.1 and Figure 2.2 show the bending diagram 1 and bending diagram 2 respectively. The descriptions are given to the labeled part the diagram.

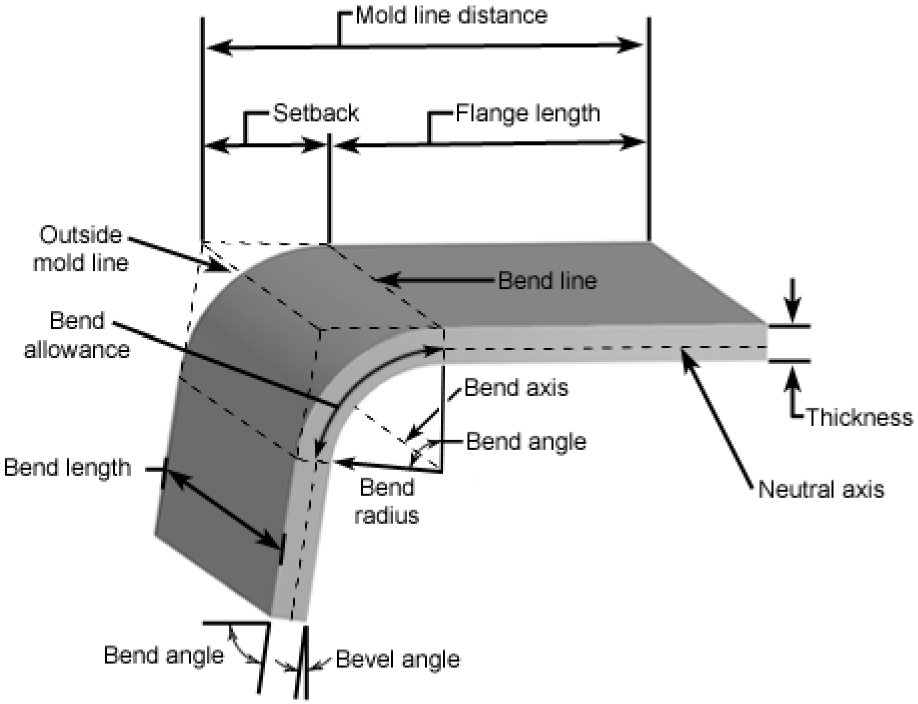

Figure 2.1: Bending diagram 1

Bend line: The straight lines on the inside and outside surfaces of the material where the flange boundary meets the bend area.

Flange length: The length of either of the two flanges, extending from the edge of the sheet to the bend line.

Mold line: For bends of less than 180 degrees, the mold lines are the straight lines where the surfaces of the flange bounding the bend area intersect. This occurs both on the inside and outside surfaces of the bend.

Setback: The distance from either bend line to the outside mold line. Also equal to the difference between the mold line distance and the flange length.
Bend axis: The straight line that defines the center around which the sheet metal is bent.

Bend length: The length of the bend, measured along the bend axis.

Bend radius: The distance from the bend axis to the inside surface of the material, between the bend lines. Sometimes specified as the inside bend radius. The outside bend radius is equal to the inside bend radius plus the sheet thickness.

Bend angle: The included angle of the arc formed by the bending operation.

Bevel angle: The complimentary angle to the bend angle.

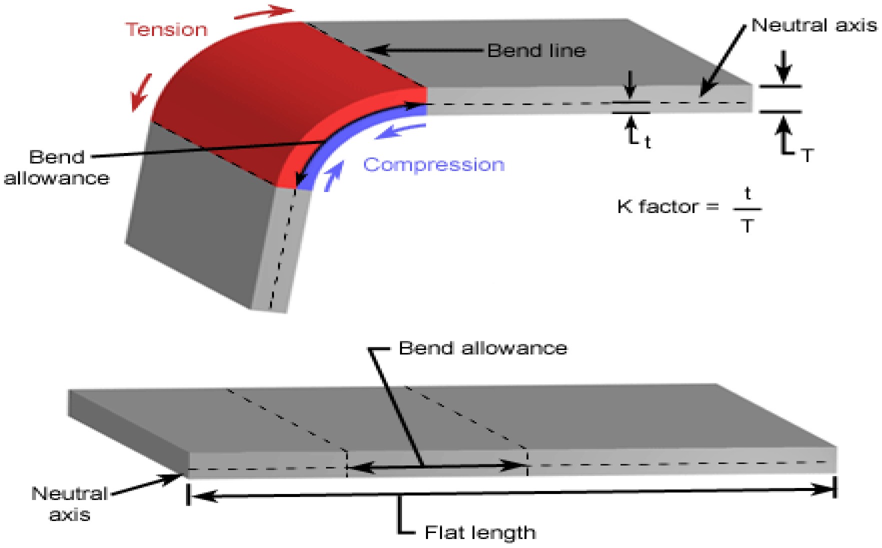

Figure 2.2: Bending diagram 2

Neutral axis: The location in the sheet that is neither stretched nor compressed, and therefore remains at a constant length.

K-factor: The location of the neutral axis in the material, calculated as the ratio of the distance of the neutral axis (measured from the inside bend surface) to the material thickness. The K-factor is dependent upon several factors (material, bending operation, bend angle, etc.) and is typically greater than 0.25, but cannot exceed 0.50.

Bend allowance: The length of the arc through the bend area of the neutral axis.

Bend deduction: Also called the bend compensation, the amount a piece of material has been stretched by bending. The value equals the difference between the mold line lengths and the total flat length.

2.3 SPRINGBACK

Sheet metal specimen required to experience cyclic loading condition in many sheet metal forming processes. The hardening behavior of materials under such conditions is more complicated than monotonic loading. The yield stress of materials in reverse loading is usually lower and the subsequent hardening rate is higher than in the case of continuous loading under Bauschinger effect. Therefore the conventional isotropic hardening model is no longer an adequate approximation.

For some materials under reverse loading, consideration of the Bauschinger effect is required for a realistic stress distribution, which is in turn essential for the prediction of springback under bending/unbending conditions (Li et al., 1999b; Geng, 2000; Geng and Wagoner, 2000).

2.3.1 Experimental Investigation Method

In order to overcome the springback phenomenon of sheet metals, the material parameters need to be identified. The data can obtained from experimental measurements of selected values for a test specimen exposed to load. Identifying of material hardening parameters can be investigated by few experimental investigation methods.

Conventional Tension-compression uniaxial experiment

The hardening parameter of material can be identified by tension-compression uniaxial experiment (Kuwabara et al., 1995; Hopperstad et al., 1995). This type of experiment will occur buckling on the specimen during the compression. The mixed hardening parameters of material have usually been determined by using cyclic torsion of metal bars or tubes which is not suitable for flat sheet metal (Omerspahic et al., 2005).

Cyclic three-point bending test

Zhao and Lee suggested a using cyclic three-point bending test to identify of the hardening characteristics. The intention of the research is to develop a simpler experimental set-up, and a methodology for identification of hardening parameters for rate-dependent and -independent materials. Figure 2.3 shows the set-up of three-point bending test. Sheet metal clamps on the both end sides by using moveable roller and shaft. The bending and reverse bending actions done clamped the bending area and move upward and downward. This type of experiments can well reduce the friction during experiment. (Omerspahic et al., 2006)

Figure 2.3: Set-up of three-point bending test

Source: Omerspahic et al. (2006)

Planar simple shear test

The cyclic shearing stress of flat sheet metal is possible to measure by planar simple shear test (Miyauchi, 1992). Yet, pure shear rarely exists in reality and principal stresses are major interests in sheet metal forming. Serious shearing will caused out-of-plane buckling on the specimens. Therefore this method is difficult to perform, although it is easy to analyze.

In-plane compression test

Kuwabara et al. presented an in-plane compression test. This test is done by sandwiched a piece of sheet metal between a pair of com-shaped dies. The male and female dies tend to slide into each other as in plane compression forces are exerted on both edges of the specimen. Therefore, the specimen can be compressed in its own plane without buckling. Frictional forces are reduced by placing Teflon films between the dies and specimen. It can enable frictional forces to be as small as possible.

In-plane tension and compression test

Balakrishnan performed an in-plane tension and compression tests. Out-of-plane buckling is prevented by applying transverse clamping forces but in-plane buckling is frequently seen upon compressive loading. The stress is not simply uniaxial due to clamping forces and friction.

2.4 HARDENING THEORIES

Even though the isotropic hardening model, and kinematic hardening rules by Prager (1956) and Ziegler (1959) well predict the proportional and monotonous loading behavior, these models cannot effectively describe the non-monotonous material deformation such as reverse and cyclic loadings. The isotropic hardening model in which the yield surface expands proportionally has been commonly adopted in the industry due to it is easy to use. But this type of models cannot describe the Bauschinger effect. To overcome this issue, Prager (1956) and Ziegler (1959) proposed the classical kinematic hardening models. However, these classical kinematic hardening models are over-predicted for the softening behavior and cannot capture several experimental observations for the cyclic loading, such as the smooth elastic–plastic transient behavior and the cyclic creep (ratcheting effect) under the stress cycles.

In the past decades, many researchers have been investigated the methods to describe the smooth transient behavior during the reverse loading. Mroz (1967) proposed the multi-surface model based on the linear segment approximation. While this model requires a large number of yield surfaces to obtain the smooth transient behavior, in order to describe the Bauschinger effect and nonlinear transient behavior. Nowadays the yield surface model by Chaboche (1986) based on nonlinear kinematic hardening and the two-surface model by Krieg (1975), Dafalias and Popov (1976) and McDowell (1985) are considered as two of the most widely acceptable models in the sheet metal forming areas. The nonlinear kinematic hardening model by Chaboche (1986) can express the smooth transient behavior by introducing an additional nonlinear back stress term to Prager’s linear kinematic hardening model. In two-surface models, the continuous plastic modulus is defined by using the bound distance between the loading and bounding surfaces having the same shape. Currently the combined isotropic-kinematic hardening model has been widely used in the sheet forming field (Chaboche and Rousselier, 1983; Khan and Jackson, 1999; Geng and Wagoner, 2002; Yoshida and Uemori, 2002), since it can depict the Bauschinger effect and the smooth elastic–plastic transition as well as the isotropic hardening effect.

Recently, the prediction capability of reverse loading and springback behavior can improve by using the modified Chaboche type combined isotropic-kinematic hardening model. It has been developed to effectively describe the Bauschinger effect and the transient behavior by Chung et al. (2005). In this model, the original Chaboche’s nonlinear kinematic hardening model has been modified by using the Ziegler type back stress based on the generalized plastic work equivalence principle to utilize general anisotropic yield stress functions. Kinematic hardening parameters are also represented as functions of equivalent strain so that they should be obtained from reverse loading tests at several prestrain levels. Still, the modified Chaboche model cannot account for the permanent softening behavior during the reverse loading, since the reverse loading curve conversed into the compressive stress by the isotropic hardening law (Kim et al., 2006).

To account for the permanent softening behavior during the reverse loading, the modified Chaboche model has been further improved by introducing the softening parameter (Lee et al., 2006). However, many materials also show the non-symmetric reloading behavior after the reverse loading stage. Since the reloading behavior is symmetric with its previous reverse loading behavior in the modified Chaboche model, the non-symmetric reloading behavior at large cyclic deformation cannot be captured.

2.4.1 Mixed Hardening Parameters

The combination of isotropic hardening law and the Bauschinger effect of the non-linear kinematic hardening law are used to describe the cyclic hardening characteristic. The pressure-independent yield surface:

$$F = f(\sigma - \alpha) - \sigma^0 = 0 \tag{2.1}$$

Where σ^0 is the current yield stress and $f(\sigma - \alpha)$ is the equivalent Mises stress with respect to the back-stress α.

The isotropic hardening component of the model defines the equivalent stress as a function of the equivalent plastic strain. The evolution can be expressed as the simple exponential law

$$\sigma^0 = \sigma_0 + Q(1 - e^{-b\bar{\varepsilon}^p}) \tag{2.2}$$

Where σ^0 is the initial yield stress at zero plastic strain and Q and b is the material parameters. Q defines the maximum change in the size of the elastic range and b is the rate at which the elastic range develops.

The non-linear kinematic hardening component describes the Bauschinger effect by describing the translation of the yield surface in stress space through the back-stress such that straining in one direction reduces the yield stress in the opposite direction. This law is defined as an additive combination of a linear term and a relaxation term, which introduces the non-linearity:

$$d\alpha = \frac{C}{\sigma^0}(\sigma - \alpha)d\bar{\varepsilon}^p - (\gamma\alpha)d\bar{\varepsilon}p \tag{2.3}$$

Where C and γ are the material parameters that are normally calibrated from cyclic test data. C is a kind of hardening modulus and γ defines the rate at which the kinematic hardening modulus decreases as plastic deformation develops.

Integration of the kinematic hardening law for monotonic loading in one-dimension yields:

$$\alpha = \frac{C}{\gamma}(1 - e^{-\gamma\bar{\varepsilon}^p}) \tag{2.4}$$

A pure isotropic hardening model and a pure non-linear kinematic hardening model can be determined from conventional tensile test stress-strain data. The total stress in uniaxial tension is the combination of the isotropic hardening component by Eq. (2.2) and the kinematic hardening component by Eq. (2.4):

$$\sigma = \sigma_0 + Q(1 - e^{-b\bar{\varepsilon}^p}) + \frac{C}{\gamma}(1 - e^{-\gamma\bar{\varepsilon}^p}) \tag{2.5}$$

The isotropic hardening parameters Q and b can be calibrated from uniaxial tensile stress-strain curves when the kinematic hardening component is neglected. Whereas the kinematic hardening parameters C and γ can be determined when Q and b are assigned zero value.

2.5 OPTIMIZATION

Decisions in a large number of optimization problems are made by use of simulation software coupled with a suitable mathematical optimization algorithm. This approach has proven to be much more efficient than the conventional trial-and-error processes (Gantar, 2002)

Optimization has been developed into a mature field that includes many branches, such as linear conic optimization, convex optimization, global optimization, discrete optimization, etc. Each of such branches has a sound theoretical foundation and is featured in an extensive collection of sophisticated algorithms and software. Optimization, as a powerful modeling and problem solving methodology, has a broad range of applications in management science, industry and engineering.

The basic idea of optimization is to minimize or maximizing a function of finding the optimal value of one or more design variable x. The function F(x) is called the merit function or objective function. The components of x are known as the design variables. The minimum point must be bracketed before a minimization algorithm can be used. The bracketing procedure consists of starting with an initial value of x_0 and moving downhill computing the functions at $x_1, x_2, x_3, ...$ until the point x_n is reach where f(x) increases for the first time.

2.5.1 Least Squares Optimization

Least squares (LS) problems are optimization problems in which the objective (error) function may be expressed as a sum of squares. Such problems have a natural relationship to distances in Euclidean geometry, and the solutions may be computed analytically using the tools of linear algebra. They also have a statistical interpretation.

Identification of the material parameters can perform by the optimization software LS-OPT. The optimization technique used relies on response surface methodology (RSM), a mathematical method for construction smooth approximations of functions in a design space. The RSM is especially advantageous for problems, in which gradients to the object function are difficult to calculate, such as in this highly nonlinear problem**.**

2.5.2 Levenberg-Marquardt Optimization

The Levenberg-Marquardt method is a regular technique used to solve nonlinear least squares problems. Least squares problems arise when fitting a parameterized function to a set of measured data points by minimizing the sum of the squares of the errors between the data points and the function. Nonlinear least squares problems arise when the function is not linear in the parameters. Nonlinear least squares methods involve an iterative improvement to parameter values in order to reduce the sum of the squares of the errors between the function and the measured data points.

The Levenberg-Marquardt curve-fitting method is actually a combination of two minimization methods: the gradient descent method and the Gauss-Newton method. In the gradient descent method, the sum of the squared errors is reduced by updating the parameters in the direction of the greatest reduction of the least squares objective. In the Gauss-Newton method, the sum of the squared errors is reduced by assuming the least squares function is locally quadratic, and finding the minimum of the quadratic. The Levenberg-Marquardt method acts more like a gradient-descent method when the parameters are far from their optimal value, and act more like the Gauss-Newton method when the parameters are close to their optimal value. This document describes these methods and illustrates the use of software to solve nonlinear least squares curve-fitting problems

Gradient Descent Method

The steepest descent method is a general minimization method which updates parameter values in the direction opposite to the gradient of the objective function. It is recognized as a highly convergent algorithm for finding the minimum of a simple objective function (Lourakis, 2005; Madsen et al., 2004). For problem with thousands of parameters, gradient descent method may be the only viable method.

Gauss-Newton Method

The Gauss-Newton method is a method of minimizing a sum-of-squares objective function. It presumes that the objective function is approximately quadratic in the parameters near the optimal solution. For more moderately-sized problem the Gauss-Newton method typically converges much faster than gradient-descent methods (Marquardt, 1963).