UNIVERSITI PUTRA MALAYSIA

NEURAL NETWORK MODEL AND FINITE ELEMENT SIMULATION OF SPRINGBACK IN PLANE-STRAIN METALLIC BEAM BENDING

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Bending has significant importance in the sheet metal product industry. Moreover, the springback of sheet metal should be taken into consideration in order to produce bent sheet metal parts within acceptable tolerance limits and to solve geometrical variation for the control of manufacturing process. Nowadays, the importance of this problem increases because of the use of sheet-metal parts with high mechanical characteristics. This research proposes a novel approach to predict springback in the air bending process. In this approach the finite element method is combined with metamodeling techniques to accurately predict the springback.

Two metamodeling techniques namely the neural network and the response surface methodology are used and compared to approximate two multidimensional functions. The first function predicts the springback amount for a given material, geometrical parameters, and the bend angle before springback. The second function predicts the punch displacement for a given material, geometrical parameters, and the bend angle after springback. The

training data required to train the two-metamodeling techniques were generated using a verified nonlinear finite element algorithm developed in the current research. The algorithm is based on the updated Lagrangian formulation, which takes into consideration geometrical, material nonlinearity, and contact. To validate the finite element model physical experiments were conducted. A neural network algorithm based on the backpropagation algorithm has been developed. This research utilizes computer generated D-optimal designs to select training examples for both metamodeling techniques so that a comparison between the two techniques can be considered as fair.

Results from this research showed that finite element prediction of springback is in good agreement with the experimental results. The standard deviation is 1.213 degree. It has been found that the neural network metamodels give more accurate results than the response surface metamodels. The standard deviation between the finite element method and the neural network metamodels for the two functions are 0.635 degree and 0.985 mm respectively. The standard deviation between the finite element method and the response surface methodology are 1.758 degree and 1.878 mm for both functions, respectively.

Abstrak tesis yang dikemukakan kepada Senat Univeristi Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

MODEL RANGKAIAN NUERAL DAN SIMULASI UNSUR TIDAK TERHINGGA LENTURAN BALIK DALAM TERIKAN SESATAH LENTURAN RASUK LOGAM

Oleh

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Lenturan mempunyai kepentingan signifikasi di dalam industri produk kepingan logam. Lanjutan daripada itu kesan lenturan balik ke atas kepingan logam patut diambil kira untuk menghasilkan lenturan terhadap kepingan logam di dalam had toleransi yang munasabah dan menyelesaikan variasi geometrical untuk kawalan proses pembuatan. Kini, kepentingan permasalahan ini meningkat disebabkan oleh pengunaan kepingan logam yang mempunyai ciri mekanikal yang tinggi. Penyelidikan ini mencadangkan satu pendekatan novel untuk menganggarkan kesan lenturan balik didalam proses lenturan udara. Dalam pendekatan ini, kaedah unsur terhingga telah dikombinasikan dengan kaedah permodelan meta untuk menganggarkan kesan lenturan balik dengan mudah dan tepat.

Dua teknik permodelan meta, iaitu rangkaian neural dan respon permukaan model meta telah digunakan dan dibandingkan untuk menentukan secara tepat dua fungsi dimensi kepelbagaian. Fungsi pertama menganggarkan kesan lenturan balik jumlah sesuatu bahan, parameter geometri dan sudut

lenturan sebelum lenturan balik. Fungsi kedua menganggarkan pergerakan tumbukan untuk sesuatu bahan, parameter geometri dan sudut lenturan balik sesudah kesan lenturan balik. Data latihan yang diperlukan untuk melatih dua teknik permodelan meta telah diambil dengan menggunakan model unsure terhingga bukan linear dimana ia adalah berasaskan formulasi terkini Lagrangian yang mengambil kira geometri, sifat bukan linear bahan dan jalinan. Untuk menentu-sahkan model unsur terhingga ini, ujikaji fizikal telah dijalankan. Satu alogritma rangkaian neural yang berasaskan propagasi terbalik alogritma telah dibangunkan. Penyelidikan ini menggunakan rekabentuk D-optimal yang diambil dari komputer untuk memilih contoh latihan bagi kesemua teknik permodelan meta tersebut dan untuk membuat perbandingan diantara permodelan yang boleh dianggap adil.

Keputusan daripada penyelidikan ini menunjukkan penganggaran lenturan balik FEM adalah persamaan baik dengan keputusan ujikaji dan deviasi piawai ialah 1.213 darjah. Keputusan juga mendapati rangkaian neural model meta adalah lebih tepat daripada respon permukaan model meta. Deviasi piawai diantara FEM dan rangkaian neural model meta bagi dua fungsi adalah 0.635 darjah dan 0.985 mm. Deviasi piawai diantara FEM dan methodologi respon permukaan ialah 1.758 darjah dan 1.878 mm untuk kedua-dua fingsi tersebut.

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E	Young's modulus of elasticity
K	Strength coefficient
N	Strain hardening exponent
M	Bending moment
1/P	Curvature
T	Sheet thickness
N	Poisson's ratio
θ	Bend angle
W	Work done
Z	Distance from neutral axis
ANN	Artificial neural networks
NN	Neural networks
FEM	Finite element method
FEA	Finite element analysis
M	Bending moment
RESIDUAL	Residual stress
F	Deformation gradient
$d\bar{\varepsilon}^p$	Equivalent plastic strain increment
$\bar{\sigma}$	Equivalent stress
μ	Friction coefficient
Δv	Sliding velocity
LMS	Least Mean Squares algorithm
MSE	mean square error
MLP	Multilevel perceptron
β_0, β_1, β_2	Regression coefficients
ε	Approximation error
B	Coefficient vector
$\Delta\theta$	Springback
θ_1	Bend angle before springback
θ_2	Bend angle after springback

Σ_Y	Yield strength
R_P	punch radius
R_D	die radius
W_D	die width
Z	Punch displacement
STDV	Standard Deviation
Y	Measured response
$\hat{y}$	Predicted response
R^2	Pearson's correlation ratio
RE	Relative error
UTS	ultimate tensile strength
$\dot{\tau}_{ij}$	Jaumann rate of the Kirchoff stress
$\dot{\varepsilon}_{ij}$	Strain rate
S_f	Surface on which traction prescribed
$\dot{\bar{t}}_i$	Rate of the normal traction
v_i	Velocity
δL_{ij}	Velocity gradient
H'	Strain-hardening rate
α	Constant equal to 1 for plastic state and 0 for the elastic state
σ'_{ij}	Effective stress deviatoric part of σ_{ij}
$\bar{\sigma}$	Effective stress
U	Nodal displacement vector
K_T	Current tangent stiffness matrix
F	External load vector
I	Internal force vector
B_K	Stress-displacement matrix
V_K	Element volume
ΔT	Time increment
σ_1, σ_2, σ_3	Principal Cauchy stresses
σ'_{ij}	Deviatoric Cauchy stress

$\|F_{residual}\|_{\infty}$	Magnitude of the maximum residual load
$\|\delta u\|_{\infty}$	Incremental displacement
TOL	Preset tolerance
C_1 AND C_2	Constant
V_{ji}	Input/hidden weights
W_{kj}	Hidden/output weights
R	Random vector
δ_{ok}	Error signal term
F	Activation functions
Z	Single pattern vector
O_K	Output from the k_{th} neuron
D_K	Target output
GA	Genetic algorithm
IN	Input parameters
OUT	Output features
ANOVA	Analysis of variance
SS	Sum of squares
Seq SS	Sequential sums of squares
Adj MS	Adjusted mean squares
Σ^2	Variance of the response
L	Linear model
LS	Linear+squares model
LI	Linear+interactions model
FQ	Full quadratic model

CHAPTER 1

INTRODUCTION

1.1 Background

Bending in manufacturing of engineering metal sheet parts is a cost effective technique since it allows the elimination of machining and welding operations. The components produced by the sheet–metal bending range from simple to complex shapes and can be as small as certain parts for the electronic industry or as large as car bodies for the automotive industry.

Sheet metal air bending processes are one of the most frequently used manufacturing operations in industry. Air bending is a forming process with great flexibility compared to other die bending processes. With the use of only one tool set it is possible to bend sheets of various thickness and mechanical properties to different bending angles. As the tooling is retracted, the elastic strain energy stored in the material recovers to reach a new equilibrium and causes a geometry distortion due to elastic recovery, the so-called springback. Springback refers to the shape discrepancy between the fully loaded and unloaded configurations. Springback depends on a complex interaction between material properties, part geometry, die design, and processing parameters.

Nowadays, the importance of the springback problem increases because of the use of sheet-metal parts with high mechanical characteristics. The capability to model and simulate the springback phenomenon early in the new product design process can significantly reduce the product development cycle and cost.

1.2 Problem Statement

Analytical models based on materials properties and tool geometry are available to predict springback. Most of the analytical models based on a lot of simplifying assumptions due to the complexity of the problem and do not provide accurate predictions. One accurate way to predict the springback is to use the finite element method (FEM).

The finite element method is a powerful numerical technique that has been applied in the past years to a wide range of engineering problems. More recently FEM has been used to model fabrication processes. When modeling fabrication processes that involve deformation, such as sheet metal bending, the deformation process must be evaluated in terms of stresses and strain states in the body under deformation including contact issues. The major advantage of this method is its applicability to a wide class of boundary value problems with little restriction on work piece geometry. However, sheet metal forming simulation using the finite element method involves material, geometric and contact nonlinearity, which make simulation of the forming process computationally expensive.

Moreover, finite element simulation applied to the sheet metal bending process becomes a trial-and-error process in which a set of input factors is used to predict a set of output performance measures. If the desired performance is achieved, a good system design has been attained. Otherwise the process is repeated until a satisfactory set of performance measures is obtained. Unfortunately, the iterative nature of this process can result in both high computing cost and difficulties in interpretation and prediction of the results.

In order to overcome these problems this study develops a novel approach using finite element method combined with metamodeling techniques so that the springback can be accurately predicted.

One of the main objectives of a metamodel is to accurately represent the input–output relationships over a wide range of the parameter space, while being computationally more efficient than the underlying finite element simulation model. Furthermore, the concept of metamodels can be useful to facilitate understanding the relationships between springback and the factors that influence the springback. In this research, two metamodeling techniques namely the neural network and the response surface methodology are used and compared to approximate two multidimensional functions used to predict the springback and the displacement required to achieve a certain bend angle after springback.