Experimental investigation of springback in air bending process

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Abstract. Bending processes is one of the important processes in sheet metal forming. One of the challenge that faces the air bending process is springback, which happens due to the elastic recovery during unloading stage. An accurate analysis of springback during the bending process is crucial to achieve a required bend angle. This paper will investigate the springback experimentally by changing many parameters such as tested material, die opening, thickness, etc. and finding its effect on the value of springback. Additionally, the paper will investigate the effect of loading time at the end of loading stage on the springback by proposing a multistage bending technique (MBT). In MBT, the loading will stop during loading stage just before the end of this stage and it will restart again shortly after. In this study, three sheet metals with different thickness will be examined, namely stainless steel, aluminium and brass. Artificial neural network (ANN) will be utilized to develop a prediction model to predict springback based on the experimental results.

1. Introduction
In order to achieve an accurate bending process, an analysis of springback in the bending process is crucial to determine. Many studies introduced a number of analytical models based on the material properties and the tool geometry that are available to predict springback. Many studies discussed the springback for different materials, for example, Senol, et al. [1] investigated the air bending process of stainless-steel sheet of different thicknesses and bend angles through Artificial Neural Network (ANN). Experimentation of the air bending processed is also carried out and the results are used in artificial neural network development to show the probability of ANN based on experimentation. Also, Jiang, et al. [2] conducted a study to investigate the coupling effects of the bending angle of a TA18 (titanium alloy) tube and the material properties on the springback angle during NC bending. The result showed that the influence of the material properties of the titanium alloy increases with the bending angle. Han et al. [3] proposed numerical and experimental methods to investigate effects of process parameters on springback characteristics of AZ31 magnesium alloy bent profile by doing the process of applying warm tension-rotation bending. The results indicated that the relationship between the forming temperature and the springback angle seemed to be linear. Heng et al. [4] experimented the effects of forming parameters on the springback behaviors in 6061-T4 Al-alloy tube bending, the results found that the springback becomes larger with increasing of the bending velocity, the tube-die clearance, the relative bending radius, the tube-pressure die friction and relative push assistant speed. Also, Wang et al. [5] investigated the springback and neutral layer for AZ31B magnesium alloy sheet by V-bending tests at temperatures from 50 to 300 °C. The results show that the neutral layer shifts to the tension zone of the sheets. The coefficient of neutral layer (k-value) decreases with the increase of temperature.
and punch radii. Also, Lawanwong [6] used a new technology to eliminate springback of 980Y HSS sheets on U-bending process, where the bottom plate is additionally bent with a counter punch at the final stage of U-bending process. The result found were that the major mechanism of the springback elimination is ‘spring-go’ by releasing negative bending moment, which has been generated by bottom pushing-up. Wiriyakorn and Thipprakmas [7] examined a new spring-back factor for a wiping die bending process to achieve a more accurate predicted bend angle of aluminium A1050-H14 using the two-dimensional plane strain modelling of an elasto-plastic, finite element model. The result showed that the spring-back factor depended not only on the ratio of the die radius to workpiece thickness but also on the bend angle, which is the new springback factor. Gisario et al. [8] used an external-force laser assisted bending process of Grade 2 CP titanium and AA 7075 T6 aluminium sheets. The experiment showed that both metal sheets could be bent to high angles with very low sharp fillet radii and control of springback using appropriate combination of tuning the contact pressure and selective laser heating of the bending zone by irradiation with a high-power diode laser. Badr et al. [9] conducted a research in which they used Ti-6Al-4V which is a high strength titanium alloy at room temperature to apply and verify the accuracy of the model using bending processes such as V-die bending and the roll forming process and then verified it with experimental results. The model demonstrated that the springback is lower in roll forming compared to simple bending. Furthermore, Sofuoglu et al. [10] investigated the springback in the three-point bending operation of AA6082T6 tubes and formed a numerical model and the results were compared with experimental outputs to verify the results. This study specifically focuses on the springback of the three-point bend that is not used on tubes in the common industry. Gisario et al. [11] in their research used the external force laser-assisted bending of Titanium Grade-2 flat sheets to achieve sharp bending angles (>140°) with small fillet radii to analyse the influence of the operational parameters, on bending angles and fillet radii of the metal substrates. The experimental results showed that shaping of the substrates can be performed with great reliability, being springback largely minimised in broad operational ranges.

Many methods and techniques were introduced to estimate springback such as ANN [12]. For example, Inamdar et al. [13] used ANN to determine the backpropagation (BP) of error, where the ANN was subsequently trained with over 400 plane strain bending experimental data. The results showed that the accuracy of predictions depended more on the number of training patterns used than on the ANN architecture. Also, Song et al. [14] used high-strength Ti–3Al–2.5V tube as the model and studied the effects of numerical parameters on prediction accuracy and computation efficiency of springback simulation of high-strength Ti–3Al–2.5V tube with tube rotary-draw-bending. The results found were solid and continuum-shell elements predict the experimental results well; specifying damping factor typically works well in Abaqus/Explicit simulation of springback. Song and Yu [15] used the three-point bending method for the T-section beam bending process. It used ANN artificial neural network to make a prediction model along with numerical simulations using finite element method to study the effect of material properties on springback. These application examples indicate that the proposed approach could achieve an allowable straightness error. Maati et al. [16] investigated the influence of constitutive modelling on the prediction of the degree of springback in the case of a stretch bending test on titanium sheets by means of numerical simulations. It also investigated the dependence of some process parameters such as the clamping force on springback. Furthermore, Yang et al. [17], conducted a study where they used an analytical model to predict the springback in air-bending of Advanced High-Strength steels (AHSS), considering the special properties of these materials. Their study also analyses the comparison between the experimental results and predictions that indicates the detailed consideration of the properties of AHSS that affects the accuracy of the springback prediction.

Most of the studies aim to find the effect of bending parameter to predict the springback for example, Kriinniger et al. [18] in their study used different bending parameters to improve the predictability of the springback in a free bending process. The quasi-static parameter variation formed was then used to produce different punch velocities to investigate its influence on the bending process, the springback and the flat length. Erdin and Atmaca [19] used a universal testing machine with 600
V-bending mold to investigate the effects of holding force on springback behavior of 1050-H14 aluminum alloy plates annealed at 120°C for 20 minutes. The results concluded that annealing decreases springback values in all anisotropy directions and that application of holding force has a significant affirmative effect on springback values. Singh and Agrawal [20] used deformation machining to investigate the comparison of the deforming forces, residual stresses and geometrical discrepancies in Deformation Machining (bending and stretching mode) with conventional and incremental sheet metal bending/stretch forming. The experiment observed that a substantial reduction in deforming forces in deformation machining and incremental bending/forming over conventional bending/forming process.

Despite the many existing study related to springback, there is a lack of study that discuss the effect of applying the bending load at end of loading stage for different time spans and multistage bending (MBT). In this paper, after developing the relationship between the input parameters including modulus of elasticity, sheet thickness and die opening and the output parameter, namely the springback. The paper discuss the effect of the time that the load keep applying at the end of the loading stage.

2. Springback in air bending process
Sheet metal bending process consists of loading and unloading stages as shown in figure 1.

![Figure 1. Air bending process.](image)

Due to the mechanical relaxation, the sheet bending angle becomes different after removing the applied load. The change of the angle is called springback and given by equation (1).

\[ \Delta \theta = \theta_1 - \theta_2 \]  

(1)

In this research, the input variables to the ANN metamodel include material parameters and geometrical parameters. The ANN can be defined by the nonlinear relation given in equation (2).

\[ \Delta \theta = f(E, \sigma_y, k, n, t, W_d, \theta_1) \]  

(2)

Where \( E \) is the Young’ modulus, \( \sigma_y \) is the yield strength, \( k \) is the strength coefficient, \( n \) is the strain hardening coefficient, \( t \) is the sheet thickness, \( W_d \) is the die opening, and \( \theta_1 \) is the bend angle prior to springback.

3. Experimental work
3.1. experimental set up
A deformation machine A7 was adapted to apply the air bending process. The die is placed on the machine table, after set up the required sheet, the punch downwards to bend the sheet metal to 90°.
Stainless steel, Aluminium and brass were selected as target materials for the experiments, table 1 presents the properties of workpiece materials.

| Materials       | Strength coefficient (MPa) (K) | Strain hardening exponent (n) | Tensile Strength (MPa) | Yield Strength (MPa) |
|-----------------|--------------------------------|-------------------------------|------------------------|----------------------|
| Aluminium       | 870                            | 0.17                          | 483                    | 345                  |
| Brass           | 585                            | 0.21                          | 400                    | 250                  |
| Stainless steel | 1400                           | 0.44                          | 515                    | 205                  |

3.2. Design of the Experiments
The experiments were designed to investigate the springback obtained when bending the sheet metals to 90° for different bending parameters. The parameters that were varied in order to assess their effect were: material, sheet thickness and die opening. Each factor had different values, as shown in the table 2.

| Parameters levels.          | Levels                      |
|-----------------------------|-----------------------------|
| Modulus of elasticity (GPa) | 69, 110, 200                |
| Thickness (mm)              | Aluminium 2, 3.5, 6, 8, 10  |
|                            | Brass 2, 4                   |
|                            | Stainless Steel 2, 4, 6      |
| Die opening (mm)            | 20, 40, 133                 |

4. Artificial neural network
ANN are computer programs based on the neural structure of the brain. An ANN is based on a collection of connected simple units called artificial neurons which is inspired from the neural structure of the brain. It is used in machine learning and computer science. ANN functions like a human brain, as in it learns from experience. The more experience or data it is provided with the quicker and more extensively it learns hence the more knowledge it gathers; this process is also known as training. It does not learn from programming or codes like usual programs and therefore offers sophisticated, intelligent computations which are similar to the ones that human brain produces. It includes methods, tools and systems devoted to simulating human methods of logical and inductive knowledge acquisition, reasoning of brain activity for solving problems. It helps computers recognize patterns and generalize those patterns of the past into actions of the future. A trained neural network can be thought of as an expert in the category of information it has been given to analyze. This expert can then be used to provide projections given new situations of interest and answer "what if" questions. Neural networks, with their remarkable ability to derive meaning from complicated or imprecise data, can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques.

Given the function of neural networks of identifying patterns or trends in data, they are well suited for prediction or forecasting needs, and hence they are successfully used in sales forecasting, data validation, industrial process control, target marketing, customer research, risk management and so on. The specificity of the work it does is in the following paradigms: recognition of speakers in communications; weather prediction; recovery of telecommunications from faulty software; undersea mine detection; texture analysis; three-dimensional object recognition; hand-written word recognition; and facial recognition and so on. Moreover, ANN can also do everything that any computer software can do making it a very useful program that extends around different fields. Like the functions of
biological neuron, the artificial neuron is the building component of the ANN designed to simulate similar functions. The artificial neurons are also known as processing elements (PE) as they process information. Each processing element has weighted inputs, transfer function and one output and it is essentially an equation which balances inputs and outputs as shown in figure 2. The arriving signals, called inputs, multiplied by the connection weights are first combined and then passed through a transfer function to produce the output for that neuron [21].

In this study, ANN metamodel was trained using data generated experimentally for different types of materials and geometrical bending tool dimensions. Based on this metamodel, friendly, easy-to-use software can be developed to predict the springback such that the metamodel can be used in production units to reduce the number of trials needed to achieve a required bending angle after springback. The required training data for the metamodel is selected so that it can provide a wide range of information between the inputs and outputs. Twenty two experiments are carried out to generate training examples and the experiments were chosen carefully to avoid inaccurate approximation.

![Figure 2. Model of an artificial neuron](image)

These training examples are divided into two groups. The first group consists of 19 training examples and the other group has 3 examples. The second group will be used for validation. To model equation (2) using the ANN metamodel, the ANN architecture and topology such as hidden layers and the number of neurons in each layer should be selected [22]. The number of neurons in the input layer of 3 and one output layer are selected. Back-propagation architecture with one hidden layer is sufficient for the majority of applications [23], therefore, one hidden layer for the neural networks was adopted. In the validation step, the 3 testing examples were used to measure the predictive performance of the metamodels.

5. Results and discussion

5.1. Experimental results
To study the effect of material parameters on the springback amount, one material parameter was varied whereas the other parameters were kept constant. The result is shown in figures 3-5. Figure 3 shows the effect of the modulus of elasticity on the springback amount for a given bending angle before unloading. It is obvious that a lower elastic modulus values produce higher springback because they produce higher strain. Figure 4 shows the effect of the die opening on the springback, it was found that, the springback increases as the die opening increased, also, it was found that, thicker sheet metal leads to lower springback amount as shown in figure 5.
Figure 3. Effect of the modulus on the springback.

Figure 4. Effect of the die opening on the springback.

Figure 5. Effect of sheet thickness on the springback.

5.2. ANN results
The ANN results is shown in figure 6. The ANN developed model can be used to predict the springback for unseen input with acceptable accuracy.

Figure 6. ANN Results.
6. Loading time
The bending process consists of two stage loading and unloading stages. In loading stage, the load is continue applying to achieve the required bending angle. The unloading stage follow the loading stages where the load is released instantaneously after bending the sheet to the required bending angle. This paper investigated the springback under different loading conditions. Instead of release the applied load instantaneously after completing the loading stage, the load was keep applying for a certain period of time. The test was repeating for different period of times and the effect of these time period the springback was investigated. The experiments we carry out with stopping time of 0, 5, 10, 15 minutes. It found that the springback were decreases as the stopping time increased. In stainless steel of 2 mm sheet thickness and under the same parameters it was found that the springback was decreased by approximately 0.5 mm for each stopping time of 5 minutes. Figure 7, explain the direction of the tension and compression stress. In tension side, the space between atoms is larger, so it moves to the more elongated location in the tension side during stopping time.

![Figure 7. Direction of tension and compression during loading stage](image)

7. Conclusion
The paper investigated a springback in the plan-strain air bending process. To study the effect of material and process parameters on the springback an experimental study were conducted. Based on this study the following remarks are drawn: Springback decreases with the modulus of elasticity because the resistance to elastic bending increases with increasing modulus of elasticity. Springback increases with the yield stress, strength coefficient since the higher these values are the greater the resistance to plastic yielding. Alarge die opening leads to more springback than a smaller one. The most significant parameters effect the springback amount are the sheet thickness, the modulus of elasticity and the die width, respectively. Increase the time at the end of loading stage decreases the springback amount.

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