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# Experimental investigation of the influence of punch velocity on the springback behavior and the flat length in free bending

Michael Krinninger[a,*], Daniel Opritescu[a], Roland Golle[a], Wolfram Volk[a]

[a]*Technische Universität München, Institute of Metal Forming and Casting, Walther-Meißner-Straße 4, 85748 Garching, Germany*

* Corresponding author. Tel.: +49-(0)89-289-14658; fax: +49-(0)89-289-13738. *E-mail address:* michael.krinninger@utg.de

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## Abstract

A study of bending parameter variations has been performed to improve the predictability of the springback in a free bending process. At first, the influence of bending parameters on the springback behavior and the flat length under quasi-static conditions has been investigated for different sheet materials. Therefore, a tool with an integrated optical measuring system has been used to determine the influences of bending angles, radii, component widths and orientations of the bending axis to the rolling direction on the sheet. Afterwards, the quasi-static parameter variation has been extended with different punch velocities to investigate its influence on the bending process, the springback and the flat length. Based on these results an extendable metamodel for correction factors was developed.

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*Keywords:* Bending; Production; Springback

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## 1. Introduction

Free bending is a frequently used method in the stamping-bending technology. The customer requests high precision standards for bending components. Furthermore, there is a high demand for large output quantity combined with an increasing cost pressure due to international competition. More complex component geometries and the utilization of new materials pose new challenges for the producing industry. Increasing the production quantity of bending parts can be realized by an increase in the number of strokes per time interval. This results in higher processing speeds of the stamping-bending machines and causes higher punch velocities in the used bending tools.

However, the practical application shows that there is insufficient knowledge about the influences on the component shape and the geometric effects caused by changing processing speeds in the bending operations.

Typically, bending tools are set up at low punch velocities to reach the dimensional requirements of the customer. In practice, the accuracy of the bending parts decreases, if processing speed is increased from the set up velocity to processing performance. The springback of the components shows a speed-dependent behavior. Expensive and time-consuming adjustments of the bending tools are necessary to ensure the dimensional precision of the components at the applied processing speed.

The plastic deformation in bending processes can be attributed to bending stresses [1]. Bending processes can be divided into bending with straight or with rotating tool movement [2]. In this research, free bending with straight tool movement of a unilateral clamped sheet is investigated. The resulting geometry of the bending component depends mainly on the position of the tool's active elements. The bend of the component is free formed with given bending core, bending clearance and immersion depth of the punch. Therefore, the dimensions and the shape accuracy of the free bending process are lower than in die bending [3]. Fig. 1 shows the schematic representation of the investigated free bending process.

Typically, two phenomena occur in bending processes, which cause costly constructional conversions or reworks of the bending tools and downgrade the efficiency of the producing industry. On the one hand, bending components often show errors in dimensional accuracy, due to the insufficient predictability of the flat length of the unbent sheet metal blank.

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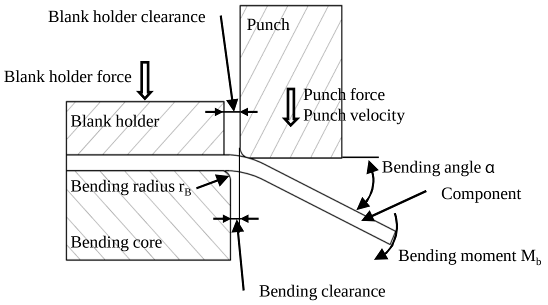

Fig. 1. Schematic representation of the applied free bending process configuration.

On the other hand, elastic springback causes dimensional deviation. To avoid these problems, special attention has to be paid already in the design phase of the bending tools.

### 1.1. Springback

In bending operations at room temperature, springback occurs and cannot be avoided. In industrial practice, experimental springback tests are used to determine springback behavior of the used materials. The results of these experiments are utilized for the construction of bending tools.

In literature, different calculation methods to predict the effect of springback are described. Either they are based on empirical tests or on analytical approaches [1]. Tables or diagrams exist, describing the experimental springback factor that can be used to calculate the springback and the overbending of the component respectively, to realize a nominal value of the bending angle. The accuracy of this prediction method is highly limited. Currently, the punch velocity is not considered in springback prediction models, as usually it is unknown.

Springback influencing parameters can be divided into three main groups: These are geometric, material and process parameters.

Geometric influences can be caused by the component or the bending tool. Bending angle, sheet width and sheet thickness are counted among the part influences. Tool influences include for example the bending core radius, the clearance between the bending core and the punch and the punch shape. An increase of sheet thickness for example leads to a reduced springback. [3, 4] Larger bending radii or higher bending angles increase the recovery. [5, 6]

Furthermore, material properties have a high impact on springback. This includes mechanical parameters like the yield strength, the tensile strength, Young's modulus and the strain hardening coefficient. Higher yield and tensile strength, lower Young's modulus and a higher strain hardening coefficient result in increasing springback. [3, 6]

Further influences on springback are the process parameters for the bending operation. These include for example the rate of forming and the orientation of the bending axis in respect of the rolling direction. The forming rate affects the springback when bending strain-rate-dependent materials. Higher forming rates lead to increased yield stresses. Therefore, springback also increases when bending with higher punch velocities. However, this effect appears especially at elevated temperatures >> 20°C and can be neglected at room temperature [7]. In contrast, [8] describes that the effect must not be neglected at room temperature. With an increasing rate of forming, the yield stress sinks to a minimum, before it eventually rises again. A reason for this behavior is the temperature-dependent softening of the material in the deformation zone, which is a result of the limited thermal conduction in the material. [8] This may lead to a local reduction of the yield stress and consequently to a decrease of recovery when bending with higher punch velocities.

In [9], the influence of different punch velocities for free bending processes of an electro-galvanized steel sheet with contact areas on both sides of the die is investigated. An increase of springback with increasing forming rate is noticed.

Regarding the springback caused by different orientations of the bending axis to the rolling direction (anisotropy), no general statements can be found. According to [3], the orientation of the sample can influence springback, because of different Young's moduli, which exist for different directions.

### 1.2. Flat length

The flat length specifies the length of the unbent blank cut and, thus, is essential for the design of the bending process. For its determination, many different approaches exist. The most common is given in [10]. Different cases have to be distinguished with respect to the bending angle. Up to now, influences of different materials and their mechanical properties, as well as geometrical settings or process-related parameters have not been investigated in detail. Hence, in practice, the flat length is only identified for specific parts.

## 2. Materials

For the research a microalloyed steel HX260LAD in 0.84 mm sheet thickness and a stainless steel 1.4310 in 1.00 mm sheet thickness have been used. Tensile tests according to [11] showed a yield strength of 294 MPa and a tensile strength of 391 MPa with a strain ≥ 26 % for the HX260LAD, which allows a high cold formability [12]. A yield strength of 1042 MPa and a tensile strength of 1460 MPa with a strain approximately 20 % [13] has been shown for the second material, the 1.4310 stainless steel. This material is used for the production of springs. The chemical composition of the used materials is depicted in table 1.

Table 1. Chemical composition in weight percentage of the used materials (max. values) according to [12, 13].

| Element<br>Material | C | Si | Mn | P | S | N | Cr | Mo | Ni | Ti | Nb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HX260 LAD | 0.11 | 0.5 | 0.6 | 0.025 | 0.025 | - | - | - | - | 0.15 | 0.09 |
| 1.4310 | 0.15 | 2.0 | 2.0 | 0.045 | 0.015 | 0.11 | 16-19 | 0.8 | 6.0-9.5 | - | - |

## 3. Experimental setup

### 3.1. Experimental testing machine

A Bihler Biflex BM 306 stamping-bending machine has been used to perform the experimental investigation. To straighten the coil material, a belt alignment system has been employed. The stamping-bending machine has a forward feed unit, a disk laser Trumpf Trudisk, which has a power of 1000 W, and a two-point eccentric press with 15 tons of press capacity. In addition, the machine has four freely movable, servo-controlled slide NC-aggregates. Each of them has a nominal press capacity of 2.5 tons. They are capable of realizing the desired test velocities from 10 mm/s up to 300 mm/s. Furthermore, the servo-control allows precise positioning of the NC-aggregates at nominal pressing force for setting up the different bending angles. It is possible to control any of the machine's modules individually and, thus, activate one tool stage after another, to prevent interference between the tools.

### 3.2. Experimental tool setup

To investigate the influence of different bending process parameters, a simple testing component geometry has been used. Various bending components of different widths and angles are shown in Fig. 2.

A four-stage linear tool has been used in the stamping-bending machine to produce the experimental parts.

The component edge trims have been cut by the laser to realize different part widths and orientations of the parts on the coil material.

The eccentric press has been equipped with a shear cutting tool to create seeker holes and to trim the components to the defined length. Seeker holes were needed to position the parts in subsequent tool stages with a high repeating accuracy. A mechanical trimming process has been chosen, to ensure an increased accuracy for the components‘ length.

The main part of the experimental tool was the bending stage to realize free bending against straight axes. A NC-aggregate has been used to do the bending operation with the desired punch velocities. The bending punch had a typical traktrix-geometry. A lever construction has been employed to generate the blank holder force via an own NC-aggregate. Variation of the punch displacement led to different bending angles. Limit stops ensured reproducible end positions for the bending punch. They had to be customized manually for different parameter variations.

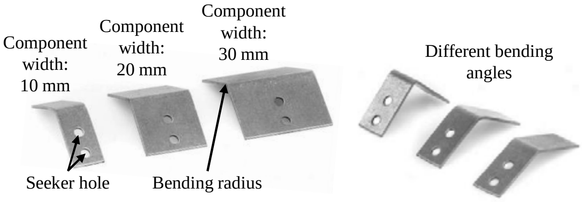

Fig. 2. Testing component geometries utilized for the experimental investigation.

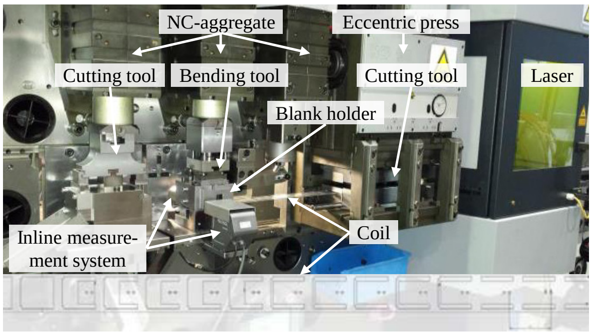

Fig. 3. Used tools for the experimental investigations and process layout for BA-RD 90°.

The setup of a bending angle has been done at a component width of 30 mm and a quasi-static punch velocity of 10 mm/s. Subsequently, component widths and punch velocities have been varied. Several bending cores have been produced to realize different bending radii. A change of bending direction with respect to the rolling direction was difficult to implement. Parts with a bending axis perpendicular to rolling direction (BA-RD 90°) could be produced directly from the belt. Components with bending axis parallel to rolling direction (BA-RD 0°) had to be cut out of the belt in unbent conditions. Afterwards, they have been positioned manually in the bending tool and bent with identical machine parameters.

Punch velocity has been virtually constant during the bending operation. The limit stops have been used to decelerate the tool quickly. The additional decelerate distance of the NC-aggregate has been provided by an integrated gas spring, so it could be ensured that the bending process was performed with a constant punch velocity.

The last tool stage was the separator stage. The cutting tool has been used to cut out the part from the belt and, consequently, for the determination of the final part length. Fig. 3 shows the testing tool and the used process layout.

Table 2 shows the bending tool parameters for both investigated materials.

Table 2. Tool parameters for the different sheet materials.

| | HX260LAD | 1.4310 |
|---|---|---|
| Sheet thickness | 0.84 mm | 1.00 mm |
| Bending clearance | 0.95 mm | 1.15 mm |
| Blank holder clearance | 1.35 mm | 1.55 mm |

### 3.3. Measuring systems and concept

A 2D-optical-micrometer manufactured by Keyence Corporation, Japan, has been integrated in the bending tool. Its measuring principle is based on collimated light emitted by InGaN LEDs on one side and a detection of shadowing by CMOS sensors on the other side. The device works independently from daylight and features a measuring accuracy within ± 2 µm. Repeat accuracy is ± 0.15 µm. The bending angles have been recorded continuously during the whole bending process. Two different bending angles have been measured:

- *Nominal bending angle for the completely closed tool* (α=15°, 45°, 60°, 90°): blank holder pushes onto the component, bending punch is in contact with the part → *bending angle before springback*.
- *Bending angle for the opened tool*: blank holder pushes onto the part, but bending punch is in neutral position → *bending angle after springback*.

Both angles have been used to calculate springback in degrees. A series of measurements for each combination of parameters (BA-RD 90°) consisted of 10 parts that have been bent consecutively. The manual test series (BA-RD 0°) consisted of 5 parts. The measurement delivered about 200 discrete values of springback for each part. They have been averaged to a single value to allow a comparison.

The tactile measurement system MarSurf XCR 20 by Mahr GmbH, Göttingen, Germany, has been used to determine the flat length of the parts. The outside contour of the bent surface has been scanned two-dimensionally. For this measurement, a single conical probe tip of 350 mm length has been used, which provides a resolution of 0.5 µm. 3 components have been measured for each of the test series. The measuring section lies exactly in the middle of the part, starting at the shear cut edge and ending at the edge of the nearest seeker hole. This section covers the elongation caused by the bending operation. The rest of the part has not been deformed. Finally, the measurements of the stretched length have been compared to the initial length of an unbent part.

## 4. Experimental design

Table 3 shows the range of the parameters, which have been varied in the experimental investigation.

Table 3. Used parameter variations for the experimental investigation.

| Material | Orientation bending axis - rolling direction (BA-RD) | Bending radius (rB) | Bending angle (BW) | Component width (bB) | Punch velocity (vB) |
|---|---|---|---|---|---|
| HX260 LAD | 90° | 1 mm | 90° | 10 mm | 10 mm/s |
| | 0° | 2 mm | 60° | 20 mm | 100 mm/s |
| | | 3 mm | 45° | 30 mm | 200 mm/s |
| | | 5 mm | 15° | | 300 mm/s |
| 1.4310 | 90° | 2 mm | | | |
| | 0° | 3 mm | | | |
| | | 5 mm | | | |

Bending radii and angle match the nominal values in the state *bending angle before springback*. After springback (second tool state *bending angle after springback*), the values are different due to the recovery.

## 5. Results of the experiments

### 5.1. Influence of the bending angle

The bending angle, at which the components are bent, has the following influence on the springback:

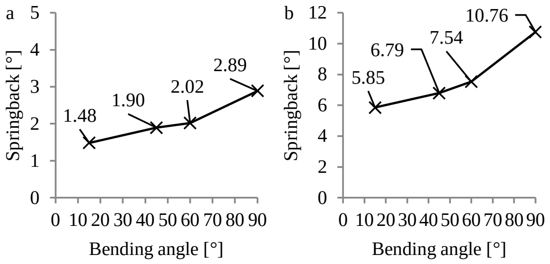

Fig. 4. Springback depending on the nominal bending angle for HX260LAD (a) and 1.4310 (b): component width 30 mm; nominal bending radius 2 mm; punch velocity: 10 mm/s; orientation of bending axis - rolling direction: 90°.

The smaller the bending angle, the smaller the springback. At a bend of 15°, the lowest values of springback can be determined. Until a nominal bending angle of 90° a nonlinear rising of recovery can be determined. Fig. 4 shows the springback of a 30 mm component width, a nominal bending radius of 2 mm and a punch velocity of 10 mm/s depending on the nominal bending angle for HX260LAD and 1.4310. The angle between the bending axis of the components and rolling direction is 90°.

1.4310 shows a higher level of springback than HX260LAD due to the higher yield strength. However, the springback of both materials show no linear correlation to the bending angle. A larger bending angle causes a larger deformation zone at the component what could explain the increased value of springback. The examination of the length change depending on the bending angle shows the expected results: The stretched length increases almost linearly with an increasing bending angle due to a higher extension with larger bending angles. The initial plane sheet of HX260LAD has a length of 40.01 mm. The bending operation to 90° leads to a part extension of 0.67 mm compared to the initial sheet length. The stainless steel shows an extension of 0.77 mm compared the unbent sheet. Therefore, the deformation zone cannot be the only reason, because then, a linear relationship between the recovery and the bending angle would be expected.

### 5.2. Influence of the bending radius

The experimental investigation for different bending radii shows the following effects on the recovery: The larger the bending radius, the larger the springback. The influence is illustrated for both materials in Fig. 5, which shows the recovery for various bending angles depending on the nominal bending radii for a component width of 30 mm. The punch velocity is 10 mm/s and the angle between the bending axis of the parts and the rolling direction is 90°.

The springback shows a nearly linear relationship to the nominal bending radius of the components. Due to an increased bending radius the zone of plastic deformation is heightened and, thus, springback raises, respectively. For HX260LAD, the changes of recovery due to higher bending radii are in the range of several tenths of a degree, whereas, for the 1.4310, the changes are in the range of integer values. Therefore, the bending radii have a significant influence on the springback behavior of bending parts.

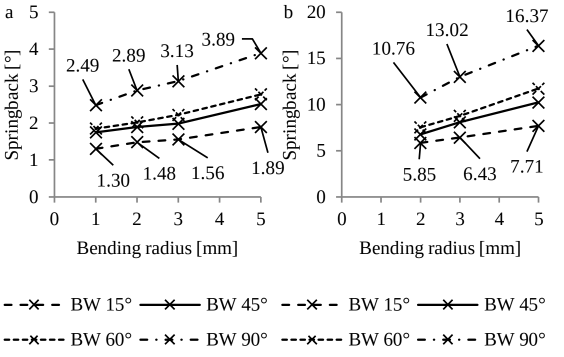

Fig. 5. Springback depending on the nominal bending radius for HX260LAD (a) and 1.4310 (b): component width 30 mm; punch velocity: 10 mm/s; orientation of bending axis - rolling direction: 90°.

The impact of the bending angle and the bending radius sum up. Large bending radii in combination with large bending angles cause an enormous springback compared to small bending angles and radii.

The measuring of the stretched length of components with different bending radii shows nearly no impact of the larger bending radii. Different radii show identical changes of the length due to the deformation. For larger radii, the extension of the component decreases, whereas the uniform plastic deformation increases.

### 5.3. Influence of component width

The investigations for different component widths show higher springback values for broader components, if bent under the same conditions. Fig. 6 depicts the springback for various component widths at different nominal bending angles for HX260LAD and the 1.4310 with a nominal bending radius of 2 mm at a quasi-static punch velocity of 10 mm/s. The orientation of the bending axis to the rolling direction is 90°.

The wide-induced changes of the springback can be determined clearly in both materials. They are in the range of several tenth of a degree depending on the bending angle. The reason for the change of the springback behavior can be found in the component state of stress. Residual stresses are responsible for the springback of bending components [1].

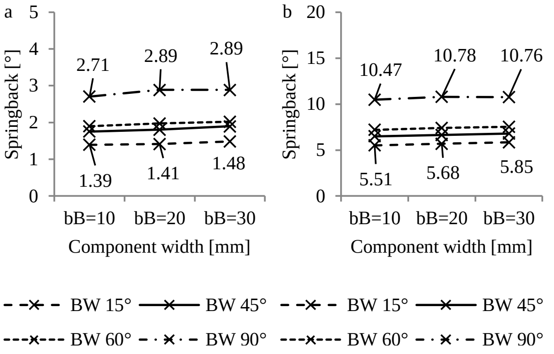

Fig. 6. Springback depending on the component width for HX260LAD (a) and 1.4310 (b): nominal bending radius 2 mm; punch velocity: 10 mm/s; orientation of bending axis - rolling direction: 90°.

At the bending operation of sheets, bulges occur in the edge region of the part. These bulges are a result of the plastic material displacement in the boundary zone due to the bending process. Material of the component inner side is displaced to the component edges. Because of the extension on the component outside, material is displaced from the edge to the inside along the bending axis. Therefore, the boundary zone of the component is bulged and the component edge is obliquely. The experimental investigations show that the bulges of the components edges with different widths are similar. They have nearly identical dimensions. Therefore, there are less stresses that contribute to the springback. However, a wide component cannot relieve so many stresses as a narrow one, so the value of springback is higher.

Interactions between the bending radius and the component width can be determined. HX260LAD shows a decreasing dependence on the component width with an increasing bending radius. At a nominal bending radius of 1-2 mm, the difference in springback is in the range of several tenth of a degree. At a bending radius of 3 mm, only a small difference is observed. A bending radius of 5 mm shows identical values of recovery for different part widths. Such interactions cannot be determined for the stainless steel. However, the 1.4310 shows consistently at the tested bending radii the component width dependence. No dependence between the stretched length of the component and the part width is noticed.

### 5.4. Influence of the angle between bending axis and rolling direction

The investigation of different orientations on the coil were used to determine the influence of anisotropy on the springback. The analysis of the two angles (0°, 90°) between the bending axis and the rolling direction shows that there is no significant impact of orientation on the springback for the used materials. There is also no influence of the orientation on the flat length. Components, which are bent in different orientations, show identical length changes.

### 5.5. Influence of punch velocity

The experimental investigation of different punch velocities between 10 mm/s and 300 mm/s shows an impact on the springback behavior of the used materials. A higher punch velocity leads to a reduction of the recovery. This is evident for both steel materials. Even though the stainless steel shows higher values of springback, the speed-dependent change of springback is significantly lower.

For the variation of the punch velocity from 10 mm/s to 100 mm/s, the largest change in springback is detected. The speed related decreases at higher punch velocities are lower.

Fig. 7 illustrates the change of springback as a function of the punch velocity at different nominal bending angles for the HX260LAD and for the 1.4310 for a component width of 20 mm and a nominal bending radius of 5 mm. The orientation of the bending axis to the rolling direction is 90°.

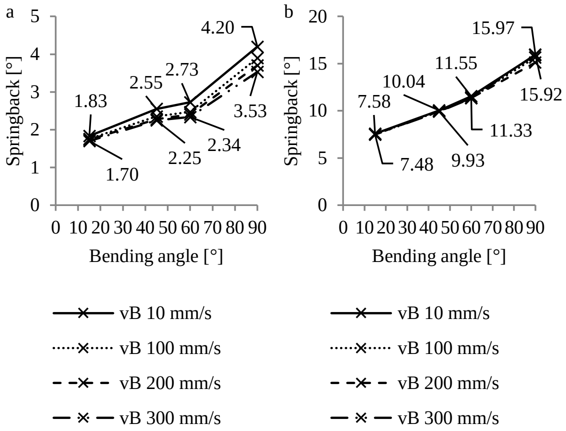

Fig. 7. Springback depending on the punch velocity for HX260LAD (a) and 1.4310 (b): component width 20 mm; bending radius 5 mm; orientation of bending axis - rolling direction: 90°.

HX260LAD shows a speed-dependent change of several tenth of a degree. The differences for small bending angles are low. Higher bending angles reveal clear differences due to the faster forming process. The stainless steel shows changes of several tenths of a degree with identical machine and tool parameters.

The experiments indicate interactions between the bending radius and the punch velocity. For larger bending core radii, a remarkable decrease of springback can be determined due to an increase of the punch velocity.

However, there is no relationship between the flat length and the punch velocity. Components formed at a higher punch velocity have the same flat length as slow formed components.

## 6. Metamodel

Based on these data, a metamodel has been developed, which allows the prediction of the elastic recovery. This metamodel calculates the springback factors from the quotient *bending angle after springback* / *nominal bending angle before springback* of the performed investigations. Via interpolation between existing nodes, the springback factor for other parameter variations can be determined. This metamodel has been subject to validation through further experimental series. It showed that the model allows for a good prediction of springback for the used materials.

## 7. Conclusion

In this experimental study, a bending tool and measuring concept have been developed to determine the influence of different bending parameters on the springback and the flat length of bending components. A parameter study has been implemented with two steel materials. The impact of the different parameters have been worked out. The influence of the punch velocity should not be neglected in the design process of bending tools, otherwise the required dimensional accuracy cannot be realized. The results of the study have been used as supporting points for a metamodel, which has been validated through further experiments.

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