Hochschule
für Technik
Stuttgart

Machine Learning for the Prediction of Brake Bending Parameters

some hyped-up tagline

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December, 2022

A dissertation submitted in partial fulfilment of the requirements for the degree of M.Sc. in Software Technology.

Abstract

This is the abstract. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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Introduction

"Sheet metal forming has been employed for centuries in diverse manufacturing industries to create a wide range of products that may be used in several applications. Among different forming techniques, sheet bending and stamping can be considered the most important variants in forming industry. These techniques have been continuously improved in recent decades to meet the growing need for lightweight metallic components in the automotive sector in order to address environmental concerns about energy efficiency and emissions [1,2]." (Cruz et al., 9 07, p. 1)

The increasing availability of data, which becomes a continually increasing trend in multiple fields of application, has given machine learning approaches a renewed interest in recent years. Accordingly, manufacturing processes and sheet metal forming follow such directions, having in mind the efficiency and control of the many parameters involved, in processing and material characterization. In this article, two applications are considered to explore the capability of machine learning modeling through shallow artificial neural networks (ANN). (Cruz et al., 9 07)

To bend a sheet metal material, different methods can be used such as air bending, coining, and bottom bending. Air bending, Figure 1a, is a process in which the punch deforms the sheet by bending without the sheet being coined against the bottom die. . Therefore, it is frequently the preferred bending method because it provides a high level of flexibility, as it is possible to obtain different bending angles using the same set of tools by only controlling the punch stroke. However, this process is characterized by strong nonlinear behavior, considering its parameters and their interrelationships [3]. In bending operations, one of the most important issues to consider is the spring- back effect. In fact, the removal of the tools causes the release of the installed residual stresses, leading to elastic recovery of the material and a change in the final bending angle. Consequently, estimating the springback effect becomes a vital requirement for achieving an accurate and regulated procedure. To address this issue, several authors tried to estimate the springback behavior in bending operations in order to develop compensation methods based on experimental, analytic and numerical approaches. (Cruz et al., 9 07)

"Sheet metal bending is a typical operation and springback is an unintended consequence of this operation. Since it causes fitting issues in the assembly, which leads to quality problems, anticipating it long before the bending operation is done is essential in today's production, so that machining parameters can be adjusted accordingly. In order to predict springback with minimum errors, this paper presents the idea for the development of machine learning models using tree-based learning algorithms (A class of machine learning algorithms). "

1.1 | Motivation

1.2 | Problem statement

With the rapid development in manufacturing and increasing demand for high-quality products, the requirement to produce parts with high precision and accuracy has become a need of the manufacturing world, since it is known that springback is an undesired outcome, so the need for minimizing this in sheet metal parts is of utmost importance, this could not be achieved by adopting traditional approaches to predicting springback, so a newer approach known as a machine learning approach is adopted. Machine learning is a branch of Artificial intelligence in which, given input data points and output value, a computer algorithm learns rules by Analyzing the data. In other words, it gives systems the ability to learn and improve themselves without explicitly being programmed. The recent advancement in technology and the development of manufacturing 4.0 also triggered the need for machine learning. It means that the machines are producing data at an unprecedented scale, so now it is needed to have fast learning algorithms that can give accurate results in a short amount of time. (Baig et al., 2021)

1.3 | Our Approach

1.4 | Document Structure

2

Theoreitcal foundations

2.1 | Sheet Metal Bending

Sheet metal "The use of sheet metal has tremendously increased due to its application in domestic and commercial appliances. By definition, sheet metal is any form of metal that has a relatively large length to thickness ratio, their thickness typically ranges from 0.4 mm to 6 mm [1]. Sheet-metals parts are formed for different kinds of applications and are now required in almost all types of equipment, whether domestic or commercial. Automobile original equipment manufacturers (OEMs) around the globe use high-tensile strength steel sheets because it provides increased strength-to-weight ratio and corresponding toughness to vehicles. Due to this reason, it is primarily used in structural parts as it provides safety and improved fuel efficiency [2]. Parts made of sheet metals are manufactured by various processes like piercing, drawing , shaping, bending, etc. Among these, the most applied manufacturing process on sheet metal is bending [3]." Baig et al. (2021)

"Bending is forming operation in which the sheet metal is forced to acquire the shapes of the cavity formed between the punch and the die. The load applied is beyond its yield strength but below its ultimate tensile strength, such that a permanent deformation is made. During this process, the metal on the outside of the neutral plane is stretched, while the metal on the inside of the neutral plane is compressed, as shown in Fig 1." Baig et al. (2021)

With the rapid development in manufacturing and increasing demand for high-quality products, the requirement to produce parts with high precision and accuracy has become a need of the manufacturing world, since it is known that springback is an undesired outcome, so the need for minimizing this in sheet metal parts is of utmost importance, this could not be achieved by adopting traditional approaches to predicting springback, so a newer approach known as a machine learning approach is adopted. Baig et al. (2021)

2.2 | Sheets and Cuboids

"Let's start by assuming you wanted to build a 90° bracket out of an infinitesimally thin sheet of material, or to be practical, a piece of paper. Because it's so thin, it actually does not contain any material, so it will bend without material deformations. To make it even simpler, we choose a bend radius of 0, which makes it a crease. In this theoretical case, the length L of the strip we need to cut out will be the sum of the two sides of the bracket, A and B." By (2016)

"If we now add a bend radius, our bracket will not consist of two straight sides A and B anymore, but by two shortened legs, which I will call a and b. The legs are connected by an arc of length c. So far, so good." To think about bending a sheet of metal that has appreciable thickness, focus on an imaginary central sheet, the so-called neutral line or neutral axis, within the thickness. This neutral line behaves just like the thin sheet above, remaining undeformed during bending. The only two things we have to bear in mind mind are that the material thickness t offsets the bend radius r′ of the neutral line by half the material thickness, and our legs a and b get a bit shorter. Real-world materials like steel and aluminum do not behave exactly like this central line, but the concept of the neutral line is still useful to describe them.

2.3 | Bending allowance and k-factor

"As always, real-world materials do not behave as simply as our models. After the material has taken on its new shape in between the hardened steel tools of the press, this central neutral line will be pretty messed up by the interaction. We can't really know the course of the neutral line after the bend without a detailed and rather complex model of the material characteristics. To make things easy, an imaginary neutral line based on a simplified approximation can be used to predict the length of the flat pattern:" "To do this, a correction factor, k, is introduced. The factor offsets the neutral line piece in the bend region from its center path until it has the length of the corresponding region of the flat pattern. The k-factor is empirically determined for a given material, material thickness, bend radius, and bending method. It reflects all real but unknown distortions in the bend region."

"Since the k-factor depends on several factors, tables of empirically determined k-factors for given setups are used. Using the k-factor, we can now calculate the bend allowance "BA", which is the length of flat material that goes into the bend region. It's simply the arc length of the "imaginary" neutral line piece, that has been offset by the k-factor:" "Of course, the approximation is only as realistic as the k-factor used, and it makes sense to keep your own table with k-values for the materials you intend to work with. However, the following values are a good starting point:"

2.4 | Springback

As illustrated in Fig 2, the punch (male part) having a concave shape pushes the sheet metal into the die (female part) having a convex shape. It causes the metal to acquire the shape of the die. When the punch is pulled back from the sheet metal, it tends to recover due to its elastic behaviour. This elastic recovery is termed as springback, as illustrated in Fig 3. Depending on the tensile nature of the material, springback can either be positive (i.e., when sheet metal recovers outward) or negative (i.e., when the sheet metal recovers inward) Baig et al. (2021)

2.5 | Bend deduction

"In practice, the flat pattern length is always shorter than the sum of A and B, so everything above can be condensed in the difference between A + B and L, which is called the bend deduction "BD"." By (2016)

“Die beim Biegevorgang stattfindende plastische Formänderung beschränkt sich dabei nicht nur auf eine reine Richtungsänderung, sondern es tritt gleichfalls eine plastische Änderung der Länge auf. So wird die dem Werkzeug zugewandte Seite des Biegeteils gestaucht, während die gegenüberliegende Seite eine Verlängerung infolge Dehnung erfährt. Dieses Verhalten während des Umformprozesses wird als Biegeverkürzung oder auch als Biegezugabe bezeichnet, je nachdem, welche Seite des Biegeteils man betrachtet.” Rockhausen (2010)

“Dabei ist diese plastische Verformung keineswegs linear und ihre Berechnung nicht trivial. Die Biegezugabe stellt einen Zahlenwert dar, der von mehreren Faktoren abhängig ist, so zum Beispiel vom Material, von der Blechdicke und den verwendeten Werkzeugen. Zwar gibt es hierfür Formeln zu ihrer Berechnung, so zum Beispiel nach DIN 6935, doch auch diese approximieren nur die in der Fertigung tatsächlich auftretenden Biegezugaben. Daher werden oft Erfahrungswerte zugrunde gelegt, die oftmals die zuverlässigere Annäherung darstellen.” Rockhausen (2010)

springback is entirely intercorrelated with the stress distribution on sheet metal as residual stresses [42]. Its behavior is also affected by material properties such as strain hardening, elastic property evolution, the presence of Bauschinger effects, elastic and plastic anisotropy, and tribology between contacting surfaces [43]. Although there are mathematical models for predicting springback in bending situations, most of them are simplistic and do not take into account all influential factors." (Cruz et al., 2021, p. 4)

2.6 |

Machine Learning "Machine learning is a branch of Artificial intelligence in which, given input data points and output value, a computer algorithm learns rules by Analyzing the data. In other words, it gives systems the ability to learn and improve themselves without explicitly being programmed. The recent advancement in technology and the development of manufacturing 4.0 also triggered the need for machine learning. It means that the machines are producing data at an unprecedented scale, so now it is needed to have fast learning algorithms that can give accurate results in a short amount of time. This need triggered engineers worldwide to build new sets of algorithms that are fast at learning and can also give reliable answers. One such group of algorithms already exist which are known as tree-based learning algorithms. A tree-based learning algorithm is a group of machine learning algorithms that are used for supervised learning." Baig et al. (2021)

2.7 | Unsupervised and Supervised Learning

2.8 | Regression

Regression Genereal

- Explain influence of a set of variables on the outcome of another variable
- Find out which input variables are the most significant influencers of the output variable
- Identify a function that explains and predicts the value of the output variable when given the values of the input variables, therefore also called function fitting: y = f(x)
- source: regression lecture

Types of regression

- Linear Regression

- Logistic Regression

Key assumption linear relationship between input and outcome variables, but input and outcome variables can be transformed to achieve a linear relationship

Regression is probabilistic, not deterministic – Probabilistic: Provides only expected values, based on probabilities, will include random errors – Deterministic: If input variables are known, output variables can be precisely determined. Examples: Newton's Laws in Physical sciences (Foundation of classical mechanics)

Model Description ...

Model Evaluation Three aspects should be investigated in model evaluation of regression models: – Overall accuracy and explanatory power of the model – Significance of each independent variable for the outcome – Confirmation of the assumptions of linear regression models

- Accuarcy: (Mean) squared error - Explanatory power (Squared correlation)

2.9 |

ML in Bending "Recently, there has been an increasing use of machine learning (ML) algorithms in various applications related to sheet metal forming to improve decision making and achieve cost-effective, defect-free, and optimal manufacturing quality [17,18]. The ML algorithms can be divided mainly in three categories: supervised learning, unsupervised learning [19], and reinforcement learning [20]. Generally, supervised learning is preferred and is used in classification or regression problems, encompassing support vector machine (SVM) algorithms, naive Bayes classifier, decision tree, the K-nearest neighbor (KNN) algorithm and artificial neural networks (ANN)." Cruz et al. (9 07)

The authors of [21] used SVM to estimate the springback of a micro W-bending process with high prediction accuracy and generalization performance. The authors of [22] compared the performance of different machine learning algorithms (multilayer perceptron type ANN, random forest, decision tree, naive Bayes, SVM, KNN, and logistic regression) in predicting springback and maximum thinning in two different forming geometries, namely U-channel and square cup. The authors concluded that the multilayer perceptron algorithm was the best in identifying the springback, with a slightly higher score than SVM. Cruz et al. (9 07)

"The literature review shows that FEM methods and Machine Learning approaches are the two techniques that are vastly applied to predict the springback in sheet metals. Since FEM is slow so it cannot be used as an on-line tool in the production line for predicting springback [29]. In machine learning, most of the earlier attempts used artificial neural networks (ANN) to predict springback, which has several limitations. Using ANN, the predictions cannot be justified easily, i.e., the explainability of the answer from the neural network is very low. Neural networks require a lot of computation power to train the model. A neural network needs a large amount of data so that the model trained is generalized, rather than overfitted or under fitted to the data." Baig et al. (2021)

"Hence, this research article used tree-based learning algorithms which have high explainability, needs less computational power, and need less data to train the model." Baig et al. (2021)

3

Research methodology

The research method used in this thesis follows the design science research (DSR) approach (von Rennenkampff et al., 2015, p. 17). DSR is a research paradigm in which the designer tries to create artifacts to answer questions for problems.

DSR is a research paradigm in which the designer creates artifacts and uses them to answer questions for problems and generate new scientific knowledge. The designed artifacts are both useful and fundamental to understanding the problem (Hevner and Chatterjee, 2010, p. 10)

Design, according to Peffers et al. (2007), is the creation of an applicable solution to a problem (Peffers et al., 2007, p.47)

According to Hevner et al. (2010) design" is both a process ("a set of activities") and a product ("artifactt"). (Hevner and Chatterjee, 2010, p.78) The design-oriented research approach as a methodological framework seems well suited to answer the research questions. Predicting spring back and bend deduction is a relevant problem in business practice. Also, the conception and implementation of machine learning models is a design activity.

The term artifacts is intentionally broad and can take on different forms. In this work, the artifact is different machine leaning models which are applied on the generated data. DSR can be implemented in various ways, a prominent example is provided by Peffers et al. and shown in Figure 3.1 The approach comprises six steps, which are dived into the superordinate phases "Build" and "Evaluate". This thesis follows these phases.

Activity 1 - Problem identification and motivation This activity includes defining a specific research problem and the value of a potential solution. The problem is used for the development of the artifact. To reduce complexity, the problem should be divided into sub-problems. For problem-solving, explicit methods such as system requirements gathering or an implicit method such as programming and/or data analysis. (Peffers et al., 2007, p. 52)

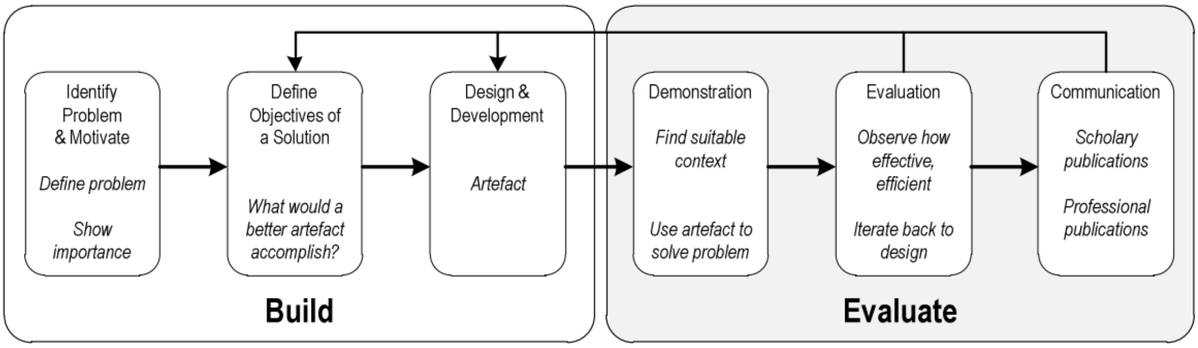

Figure 3.1: Design Science Research Approach according to Peffers et al. Picture: (Sonnenberg and vom Brocke, 2012, p. 72)

Activity 2: Define the objectives for a solution The goals of a solution are derived from the problem definition. These are derived in the context of what is possible and feasible. Objectives can be quantitative or qualitative. Objectives should be derived from the problem specification and are thus based on the previous step. For knowledge about previous solutions and their effectiveness are required (Peffers et al., 2007, p. 55)

Activity 3: Design and development This step involves the creation of the artifact. An artifact can potentially contain models, methods or constructs, it can be anything that contributes to the solution of the research question. This step includes the definition of the functionality and architecture of the artifacts, followed by the creation of them. (Peffers et al., 2007, p. 55)

Activity 4: Demonstration The use of the previously created artifactt is demonstrated for one or more problems. This requires effective knowledge of the artifact. (Peffers et al., 2007, p. 55)

Activity 5 - Evaluation It is observed and evaluated how well the developed artifact provides a solution to the defined problems in activity 1. Knowledge of relevant metrics and methods of analysis is assumed. Depending on the nature of the problem, the evaluation can take different forms. A comparison of the functionality of the artifact and other solutions can be considered. Furthermore, quantified quantified parameters can be used to measure the performance of the artifacts (Peffers et al., 2007, p. 56) Hevner et al. suggest five different evaluation methods: Observational methods, analytical methods, experiments, testing of the artifact and descriptive methods (Hevner et al., 2004, p. 87)

Activity 6 - Communication The problem and the artifactt and its benefit are communicated externally (Peffers et al., 2007, p. 56) Hevner et al. describe in a conceptual framework guidelines for the

3.1 | Design Principles

Design Principles (DP) are seen as a central part of design-oriented research. (Gregor et al., 2013, p. 348) Design principles are characterized as "principles of form and function" as well as "principles of implementation" of an artifact. (Gregor and Jones, 2017, p.8) They are used to close the gap between researchers and user and allow prescriptive research on systems. They are used to capture knowledge about the artifact. (Sein et al., 2011, pp. 37-56). Koppenhagen et al. suggest generating design principles by grouping requirements for the solution and then creating core requirements, which can which can then be DPs. (Koppenhagen et al., 2012, p. 6)

3.2 | Evaluationn of Machine Learning Models

tbd...

3.2.1 | Goal Question Metric Approach

To make the defined quality attributes measurable, the “Goal-Question-Metric”-approach (GQM) was chosen in this work, which is one of the most common approaches and is divided into three levels: (Basili et al., 2002, p. 3).

1. conceptual level (goal): A goal, which usually corresponds to a quality criterion, is set for an object.

2. operational level (question): Questions are asked to define how an objective can be achieved.

3. quantitative level (metric): A set of data is associated with each question with the aim of answering it. Depending on the question, the data can be collected and evaluated objectively or subjectively.

Objectives, questions and metrics can be presented in a hierarchical structure.

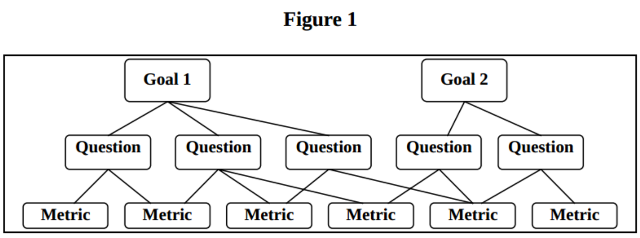

Figure 3.2: Goal-Question-Metric Ansatz (Basili et al., 2002, p. 3)

4

Build

4.1 | Dataset Generation

This work focuses on two parameters, which are important for metal sheet bending. Spring backk and bend deduction. The following describes the experimental setup used for the experiments performed.

4.2 | Dataset generation

For the dataset generation, bending experiments were performed on metal sheets with different thicknesses. The material used is cold rolled steel sheets of the norm DIN EN 10130. The thicknesses used were 0.5mm, 1mmm and 2mm. The material was used because it is commonly used in bending processes and its high availability. In previous tests, it was observed, that the spring back and bend deduction are well observable with this material. Using this material, 200 single bending pieces of the dimension 50×100 mm have been cut. Each piece was bend one time using a *XXXX* brake bending machine. The bend parts where digitalized using a scanner and the resulting images were measured with image processing software ImageJ.

4.2.1 | Measurement of the parameters

The two main parameters in the dataset are the *spring back* and the *bend deduction*. The following describes how these were measured and possible limitations of the used methods.

Springback: The brake bending machine used for the experimental setup was set to an angle. After the bending operation, the metal sheet sprung back. To get the spring back, the angle after the bend was measured with a protractor and subtracted from the angle, that was set in the machine. The angle was measured another time digitally using the *ImageJ* software to minimize the margin of error.

Bend deduction: Measuring the bend deduction is more complex. After a metal sheet is bent, it is hard to measure the flat pattern length because the material is malformed at the bent. As a result, the neutral axis is not in the center of the sheet and hard to measure, but it can be calculated using different approaches. There are multiple ways to measure the bend deduction described earlier. In this setup, the method described in the DIN6395 was used. This method uses a k-factor which is an approximated value and therefore and therefore it can be inaccurate. (Equation 4.1).

$$k = 0.65 + \frac{1}{2} \log \frac{r}{s} \tag{4.1}$$

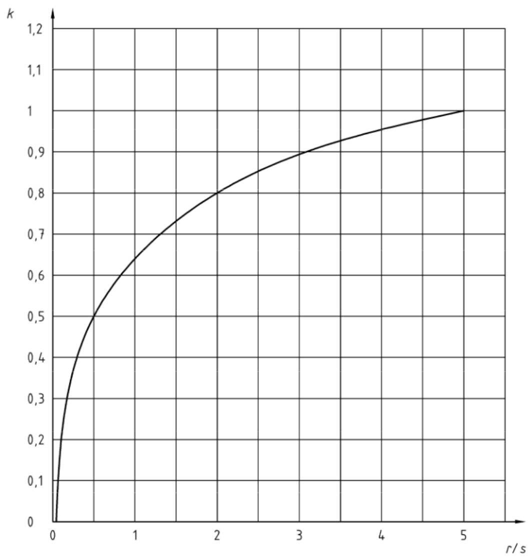

Figure 4.1: Graphical representation of the correction factor.

The DIN 6935 used the formula for the stretched length, $length = a + b + v$ where a and b are the side lengths of the sheet and v is a correction value for the deduction. DIN (2011) The stretched length is measured different depending on the bending angle.

Opening angle $\beta 0^\circ$ **to** 90° For opening angles between $0^\circ$and 90° the side lengths a and b are dimensioned from the tangent of the bend to the edge. To calculate the compensation value v (Equation 4.2) is used DIN (2011).

$$v = \pi * (\frac{180^\circ -}{180^\circ}) * (r + \frac{s}{2} * k) - 2(r + s) \tag{4.2}$$

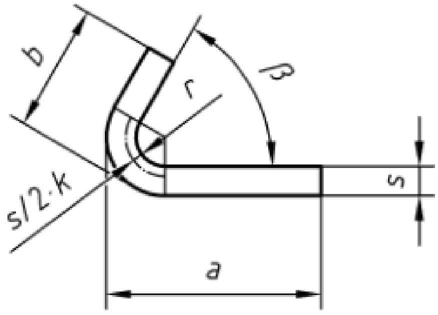

Figure 4.2: Opening angles $\beta 0°$ to $90°$ DIN (2011)

Bending angle $\beta 90°$ to $165°$ (Equation 4.2) For opening angles between 90° and 165° the side lengths a and b are dimensioned from the apex to the edge. To calculate the compensation value v (Equation 4.2) is used. DIN (2011)

$$v = \pi * (\frac{180° -}{180°}) * (r + \frac{s}{2} * k) - 2(r + s) + \tan\frac{180° - \beta}{2} \tag{4.3}$$

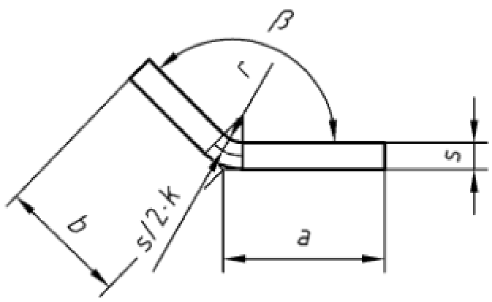

Figure 4.3: Opening angles $\beta 90°$ to $165°$ DIN (2011)

For opening angles between 165° and 180° the compensation value v is 0. The values for v would be negligibly small. DIN (2011) The side lengths a and b where measured using the software *ImageJ*.

Edge cracking is not measured for now because the steel used has no high-strength and with machine in usage it was not possible to create edge cracking.

- 200 samples where created with the measurements 50x100mm
- Each sample was folded one in half so that 50mm where before the bend and 50mm after.

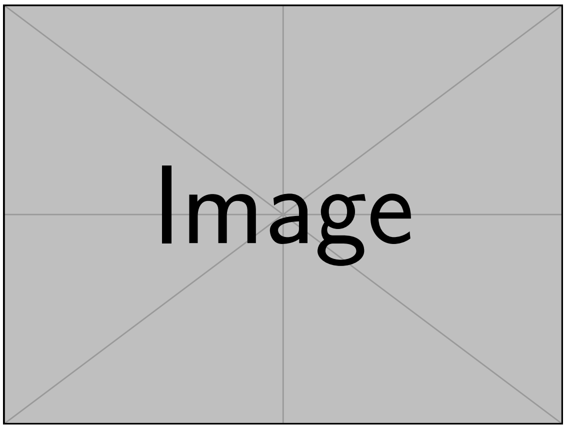

Figure 4.4: Screenshot ImageJ

Parameters	Mechanical Press
Load Tonnage (T)	tbd...
Material	JSC440, JSC590, JSH440, JSH590
Thickness of blank (s)	1.0 mm, 1.2 mm, 1.4 mm, 1.6 mm
dimensions of plate (w)	50 mm, 100 mm
Bend angle	60, 90 and 120

Table 4.1: Parameters for the experimental setup

-
-
- Recycled afterwards
-

4.2.1.1 | Measurement

Bend deduction

- The bending line was marked
- After the bend a Caliper was used to measure the side lengths (A + B).

4.3 | Computational Setup

4.4 | Model Selection

4.5 | Model Training

5 Evaluation

In an ideal world, you should have two kind of evaluations. The first is against some ground truth (perhaps a random model?). The second kind of evaluation is against other people's work (accuracy, speed, etc.). Any dimension which is of interest, should be evaluated. Evaluation should be statistically sound.

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

This is the second paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

After this fourth paragraph, we start a new paragraph sequence. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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5.1 | Summary

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

6

Conclusions

This section should have a summary of the whole project. The original aims and objective and whether these have been met should be discussed. It should include a section with a critique and a list of limitations of your proposed solutions. Future work should be described, and this should not be marginal or silly (e.g. add machine learning models). It is always good to end on a positive note (i.e. 'Final Remarks').

6.1 | Revisiting the Aims and Objectives

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

6.2 | Critique and Limitations

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

6.3 | Future Work

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

6.4 | Final Remarks

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

References

Baig, S. U. R., Wasif, M., Fatima, A., Baig, M. M. A., and Iqbal, S. A. (2021). Machine Learning for the Prediction of Springback in High Tensile Strength Steels after V-Bending Process Using Tree-Based Learning. Preprint, In Review.

Basili, V. R., Caldiera, G., and Rombach, H. D. (2002). THE GOAL QUESTION METRIC APPROACH. *NA*, page 10.

By (2016). The Art And Science Of Bending Sheet Metal.

Cruz, D. J., Barbosa, M. R., Santos, A. D., Miranda, S. S., and Amaral, R. L. (2021-09-07). Application of Machine Learning to Bending Processes and Material Identification. *Metals*, 11(9):1418.

DIN (2011). DIN 6935:2011-10, Kaltbiegen von Flacherzeugnissen aus Stahl. Technical report, Beuth Verlag GmbH.

Gregor, S., Hevner, A. R., and University of South Florida (2013). Positioning and Presenting Design Science Research for Maximum Impact. *MIS Quarterly*, 37(2):337–355.

Gregor, S. and Jones, D. (2017). THE ANATOMY OF A DESIGN THEORY. *College of Business and Economics The Australian National University*, page 60.

Hevner, March, Park, and Ram (2004). Design Science in Information Systems Research. *MIS Quarterly*, 28(1):75.

Hevner, A. and Chatterjee, S. (2010). *Design Science Research in Information Systems*, volume 22, pages 9–22. Springer US, Boston, MA.

Koppenhagen, N., Gaß, O., and Müller, B. (2012). Design Science Research in Action - Anatomy of Success Critical Activities for Rigor and Relevance. *NA*.

Peffers, K., Tuunanen, T., Rothenberger, M. A., and Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems*, 24(3):45–77.

Rockhausen, A. (2010). *Integration von SolidWorks in die Prozesskette Blech unter Einbeziehung von Inventor-Modelldaten*. PhD thesis, Hochschule Mittweida.

Sein, Henfridsson, Purao, Rossi, and Lindgren (2011). Action Design Research. *MIS Quarterly*, 35(1):37.

Sonnenberg, C. and vom Brocke, J. (2012). Evaluation Patterns for Design Science Research Artefacts. In Helfert, M. and Donnellan, B., editors, *Practical Aspects of Design Science*, volume 286, pages 71–83. Springer Berlin Heidelberg, Berlin, Heidelberg.

von Rennenkampff, A., Nissen, V., and Stelzer, D. (2015). *Management von IT-Agilität: Entwicklung eines Kennzahlensystems zur Messung der Agilität von Anwendungslandschaften*. Number Band 2 in Ilmenauer Schriften zur Wirtschaftsinformatik. Univ.- Verl. Ilmenau, Ilmenau.