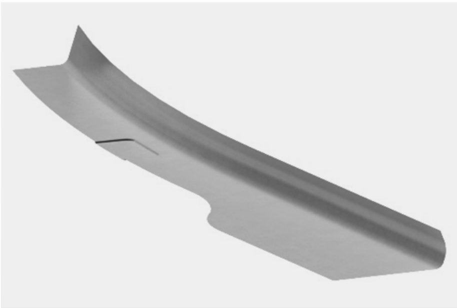
PROTECH
INSTITUT DER UNIVERSITÄT SIEGEN

UNIVERSITÄT SIEGEN

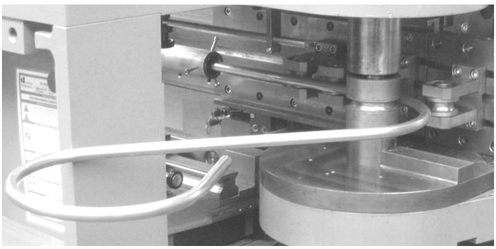
CHAIR OF FORMING TECHNOLOGY

Univ.-Prof. Dr.-Ing. Bernd Engel



UMFORMTECHNIK UTS SIEGEN

BIEGENINSIEGEN



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Preface

The chair, founded in 2004, has achieved international recognition under the label "Biegen in Siegen". With 15 scientific employees and approx. 8 assistant scientists we exclusively work on topics of bending of profiles and tubes.

In three working groups we have overwritten our contents with

- Process control and cyberphysical systems
- Bending of tubes and profiles of metallic materials
- Bending of tubes and profiles of fibre reinforced thermoplastics

The UTS conducts application-oriented research in order to address current industrial issues in basic research and to make industrial research useful. The close connection to industry is often the starting point for innovation and also the motivation for basic engineering research.

A special competence of the chair is process development for future requirements. Especially the changing products and batch sizes require a paradigm shift in forming technology. Dissolving of tools, mastery of the bending process and digital interlinking from semi-finished products to the forming machine are developed in a methodical way and tested in an industry-oriented laboratory environment. The goal is scalable production, which in one configuration allows variance in geometry, material and semi-finished product geometry. With increasing individualization of the products, questions regarding machine setup and integration of the customer into the process also play an increasing role.

In an industry-oriented laboratory we are able to demonstrate cyberphysical solutions for straightening, applications of individual product manufacturing and the validation of process developments. For this purpose the chair has three rotary draw bending machines, two three-roller bending machines, one swivel bending machine and two presses at its disposal.

Teaching, especially in the topics of student research projects, bachelor and master theses, is usually closely related to the current research focus and development projects.

Siegen, March 2021

Univ.-Prof. Dr.-Ing. Bernd Engel

1. Cyber Equipping 4.0 - EFRE Leitmarktwettbewerb Produktion.NRW

Project manager and coordinator: Dr.-Ing. Christopher Kuhnhen

Editor: Linda Borchmann, M. Eng.

Today's procedure for machine setup

Today, the equipping of machining tools on production machines is usually carried out by highly qualified skilled personnel. The skilled workers involved (usually machinists, industrial mechanics or toolmakers) set up the machines on the basis of their professional training, plus experience they have usually acquired themselves, based on learning by doing. As soon as there are changes in the tool geometry or an adaptation of the tools on another machine, this experience knowledge can only be used to a limited extent. In particular, modern production machines with extensive control and regulation options require good training on the machine itself in order to avoid serious errors, for example due to machine crashes.

Project innovation Cyber Equipping 4.0 - Tool assembly and machine setup with setup navi

The aim of the joint project was to support the machine operator with a cyber-physical system during the setup of the bending forming process selected as an example. The core object was the development of a demonstrator guidance system, which supports the operator in setting up the machine and prepares complex factual and comprehension contexts on the basis of which the machine operator can orientate himself.

The setup support was implemented as so-called Expert to Go within the framework of the function demonstrator. This Expert to Go comprises the Static Expert Module (SEM) on the one hand and the Dynamic Expert Module (DEM) on the other.

Both subsystems operate independently on different platforms. The SEM uses the MS-HoloLens augmented reality glasses for visualization, which show the operator the assembly sequence of the individual tools and joining and connecting elements with the aid of tables, instructions, images and videos displayed as holograms. It works as a kind of navigation system.

Following the project

Currently, there are no known methods that enable an experienced machine operator to teach a complex manufacturing process into a cyber-physical tool. Both the creation of an interactive AR instruction and the initialization of a self-learning system represent the greatest innovations, in addition to the first coherent consideration of the complete setup process - consisting of static and dynamic setup components. The valuable expertise of the skilled workers is used to create instructions for the

Figure 1.1: Supported by the European Regional Development Fund in the funding procedure EFRE.NRW Produktion

static setup process on the one hand and to derive the configurations and interrelationships of the manufacturing process on the other hand and to transfer them into a self-learning system. Thus, for the first time, a comprehensive framework is made available with which companies can capture knowledge-intensive static and dynamic setup processes on the basis of existing experience and subsequently make them available again, enriched by process data.

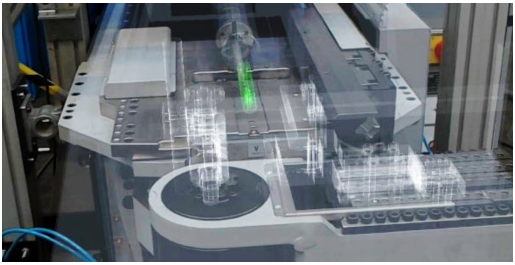

Figure 1.2: View through the glasses: Support of the machine operator during setup of the production process by means of hollo-gram display on real machine body

This goal was further pursued with the project partners and completed the setup support after the end of the funding phase. Currently, the project "Laara" - Learning, Informing and Competent Acting with Augmented Reality in the Work Process (BMBF) investigates how the behavior in dealing with AR in training can take place. Among other things, the findings on informal learning in the workplace are taken into account. However, it remains to be investigated to what extent these findings, theories and research methods are transferable with respect to semi-virtual workspaces and what consequences result for the organizational design of workplaces and the didactic design of learning in the work process. First research results will follow shortly. (laara.info)

Major publications on forming technology

- Abele, N.D.; Hoffmann, S.; Kuhnhen, C.; Ludwig, T.; Schäfer, W.; Schulte, L.; Schweit-zer, M. und V. Wulf (2016): Unterstützung des Rüstprozesses durch cyber-physische Hilfsmittel am Beispiel des Rohrbiegeprozesses. Konferenz: Zukunftsprojekt Arbeitswelt 4.0, Ministerium für Wirtschaft, Arbeit und Wohnungsbau in Kooperation mit den Forschungsinstituten IAW, ZEW, IAO, ISI und Universität Hohenheim, Stuttgart.
- Schulte, L.; Kuhnhen, C.; Abele, D.; Hoffmann, S.; Pinatti de Carvalho, F.; Engel, B.; Schweitzer, M; Wulf, V. (2017): Cyber equipping 4.0 - FE-simulation-based setting instructions for a rotary draw-bending machine. In: XIV International Conference on Computational Plasticity. Fundamental and Applications, COMPLAS 2017, Barcelona, Spanien, 05.-11.09.2017, ISBN: 978-84-946909-6-9, S. 754-765
- Hoffmann, S.; Abele, N.-D.; Kuhnhen, C.; Ludwig, T.; Schäfer, W.; Schulte, L.; Schweitzer, M.; Wulf, V. (2017): Herausforderungen des Wissensmanagements im Rahmen betrieblicher Rüstprozesse Konferenz: Zukunftsprojekt Arbeitswelt 4.0, Ministerium für Wirtschaft, Arbeit und Wohnungsbau in Kooperation mit den Forschungsinstituten IAW, ZEW, IAO, ISI und Universität Hohenheim, Stuttgart.
- Kuhnhen, C. (2018): Cyberrüsten 4.0 – Fachvortrag. 2. Technologietag Umformtechnik am Automotive Center Südwestfalen, Attendorn, 14.03.2018

- RTL-West. Sendung am 19.09.2018, 18 Uhr, http://www.rtl-west.de/beitrag/artikel/brille-mit-effekt/ und http://www.rtl-west.de/livestream/sendung/2018-09-19/PGM1909/
- Borchmann, L.; Kuhnhen, C.; Engel, B. (2019): Sensitivity analysis of the rotary draw bending process as a database of digital equipping support, SheMet 2019, Leuven, Belgien, 15.-17.04.2019

2. Center for Smart Production Design Siegen (SmaPS)

Editor: Jonas Knoche, M. Sc.

Industry 4.0 – regional and transparent for a promising middle class

The term of industry 4.0 is on everyone's lips, not least because of the Federal Government's strategic focus on the research priority Industry 4.0. Nevertheless, the term Industry 4.0 remains a difficult or even impossible to grasp uniform term for the medium-sized industrial companies in the region of South Westphalia, as numerous discussion groups and scientific conferences in recent years have shown. As it turns out the term Industry 4.0 is often connected with holistic restructuring of the production and accompanying immense investments. Specifically, it is feared that newly purchased Industry 4.0 capable machines cannot be integrated into existing network infrastructures and for a sufficient exchange of information new network infrastructures are needed.

In this context a center for Smart Production Design is established at the University of Siegen. The aim of this research infrastructure is the development and construction of intelligent tools and operating equipment. The idea is to enable small and medium enterprises in the region of South Westphalia to have a transparent access to the technologies of Industry 4.0 and at the same time to promote their international competitiveness. This approach is promising because the level of integration chosen with the tools and operating equipment arises from the need for new tools for new products. Besides the evolution of the used tools and operating equipment humans are integrated as workers 4.0 into the production landscape of industry 4.0.

Use of innovative technologies for intelligent tools and operating equipment

Innovative manufacturing technologies are procured for the construction of intelligent, Industry 4.0-capable tools and operating equipment. With the use of additive manufacturing technologies limitations of traditionally manufacturing technologies are repealed, which enables completely new design possibilities. The main interest here is the integration of sensors and actuators.

A system based on active thermography is used for the non-destructive testing of additively manufactured structures. The aim is to detect any internal component defects. The investigation of the mechanical behavior during operation will be performed with an optical measuring system for strain and stiffness measurements.

It is intended to use a motion capture suit as well as a device to detect human movement for the immersion of humans as workers 4.0 into the production landscape of industry 4.0. With this assembly and handling processes during production and machine handling are captured and recorded.

Concept for demonstration tool

The qualification of the procured technologies is carried out with the construction of demonstrators in the form of forming tools. As a first concept a simple pressure tool with a segmented bottom part structure is planned, see following figure.

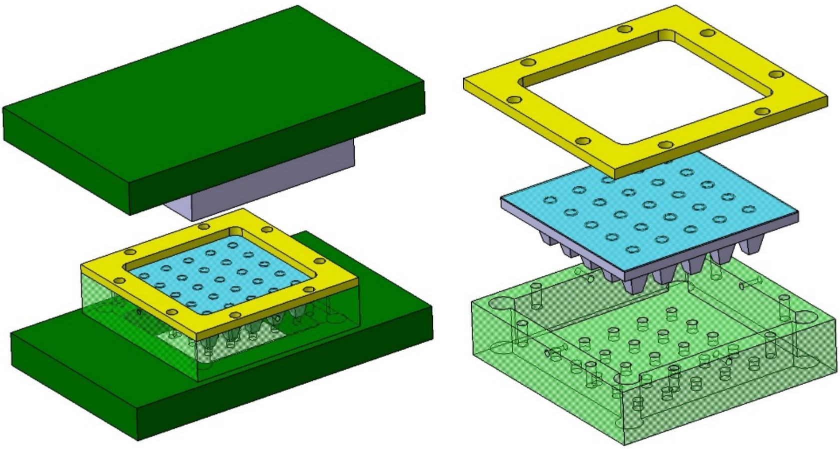

Figure 2.1 Konzept für erstes Demonstratorwerkzeug

Centerpiece of this concept is the segmented structure in the countersink of the pressure tool. The structure is designed in such a way that the flat upper side can be elastically deformed by an appropriate lining at the stumps of the pyramids. By changing the surface topology, the surface pressure curve that occurs under load should be influenced.

3. Technical enhancement of rotary-draw-bending to a semi-kinematic process with reduced tool surfaces

Funding programme: DFG
Funding code: EN 698/9-1
Editor: Christopher Heftrich

Motivation

Shape-bound forming processes such as rotary draw bending are suitable for creating complex shaped profiles. The range of applications includes a multitude of bending geometries, which are used in industrial and private applications. The main advantage is that small bending radii can be produced: Bending radii smaller than 1x pipe diameter are achievable.

In rotary draw bending, the tool surfaces are determined by the semi-finished product dimensions - circumference and wall thickness - and the bending geometry with regard to the bending radius. According to the product variety, the tooling costs increase. In addition, the design and manufacture of the partly double-curved tool surfaces of the bending die is complex. Even more, the material-related springback, which results from the elastic deformation after the bending process, must be taken into account when laying out the die. However, this can only be estimated, so that reworking of the tool geometries may be necessary.

Goal

The aim is to extend the tool-bound rotary draw bending to a partly kinematic process with reduced tool surfaces. In this way, demands for further flexibilization of the forming processes and the economic production of smaller quantities towards individualized products will be met.

The tool geometries adapted to the semi-finished product and the bending radius in rotary-draw bending need to be investigated with regard to the flexibilization of the bending process. For validation purposes, bending experiments are planned. Therefore, tubes with different cross section diameters as well as various bending radii are tried out at the reduced or geometrically simplified tool surfaces with the extended tool kinematics.

In addition, these tools should allow to actively influence the bending process . Therefore, they could be operated as actuators within a controlled rotary draw bending process. The basis for this approach is to simplify the geometry of the die cavities. which allows to design the bending form in two parts. In this case the load, which occurs in the bottom of the cavity, needs to be transferred to another area. Among other things, this opens up the possibility of actively vary the distance between the tool halves during the forming process and thus change the effective bending radius. In addition, it is also possible to adapt the shape to fluctuations in tube diameters. Semi-finished products are made of materials that have an elastic sprig back, which leads to shape deviations of the product after bending. The change in the bending angle is compensated by bending a larger bending angle under load. The springback also leads to an increase in the bending radius. Shifting the split bending form against each other provides a new degree of freedom to compensate this effect.

Approach

1. Determination of the contact area

When bending, the tube initially lies against the bending form only in a very small zone. This contact area increases as the bending angle increases. FE-simulations show no constant contact normal stresses, neither with respect to the circumference of the cavity nor with respect to the bending angle. The area in contact with the tube is denoted effective area. This is a part of the area of the cavities of the tools and varies as the process progresses.

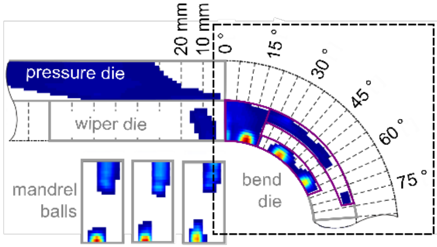

Figure 3.1: Determination of the contact area between bent tube and conventional rotary draw bending tools

2. Reduction of tool surfaces to contact surfaces and analysis of individual segments

Variations of tool geometries will cause changes of active surfaces and prevailing contact normal stresses. Therefore, geometries of the tube cross sections will change. Current strictly shape related tool cavities are made to compensate shape deviations. However, changes in tube cross sections cannot be suppressed completely and tend to occur within the bend. The extrados of the bent tube may collapse and the initially circular cross section will become oval. The extent of these cross-sectional changes depends on the bending process and is also influenced largely by properties of semi-finished product.

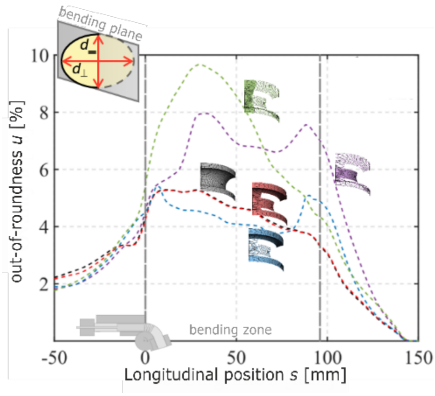

Figure 3.2: Reduction of tool surfaces to contact surfaces and analysis of the influence of individual segments on the cross section deformation

3. Simplification of the tool surfaces

The geometric simplifications of the tool surfaces lead to higher local surface pressures (similar to Hertzian pressures) with lower effective surfaces due to the osculation to the tube. An essential result of the investigations are correlations between the simplifications of the tool geometries and the changes of the cross sections of the tube bends.

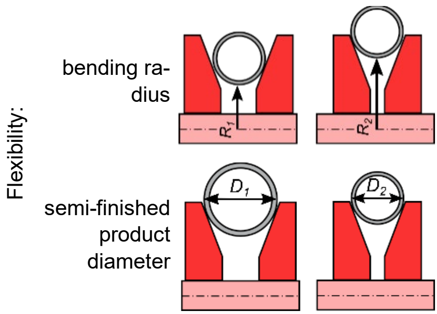

Figure 3.3. Simplification of the tool surfaces

Major publications on forming technology

Heftrich, C., Engel, B., Steinheimer, R. (2018). *Rotary-draw-bending unsing tools with reduced geometries.* Metal Forming 2018, Toyohashi, Japan

4. Control of the material flow to increase component quality in rotary draw bending

Editor: Linda Borchmann, M. Eng.

Motivation

Rotary Draw Bending is a profile bending process which is preferably used for small wall thicknesses and small bending radii. Limits of the process are cracks on the outer bend and wrinkles on the inner bend. Measures to prevent the formation of wrinkles are carried out on the one hand by geometric changes to the tool positions of the wiper die, the mandrel and the pressure die, and on the other hand by corrections to the axis movements (pressure die, collet and pressure die feed). These corrections are made in each case after the production of a wrinkled component. The formation of wrinkles is an instability that can only be calculated imprecisely due to the variety of its influences.

Objective

The objective is to detect the formation of wrinkles during the forming process at such an early stage that it is possible to stabilize the process by means of extended adjustment options. A means of detecting wrinkles as they form is being developed and tested. If the process enters this instability, the tool forces or positions are adjusted in a controlled manner.

In situ detection of wrinkle formation

A laser line scanner and load cells were used in practical bending tests to detect not only the heights and spacing of wrinkles, but also the position and timing of the first wrinkle, see Figure 4.1. The laser line scanner was used to measure the tube contour in the straight tube area in front of the transition plane. A load cell recorded the normal force of the wiper die, and a tension-compression sensor recorded the mandrel force in the longitudinal direction of the tube. The manipulated variables infeed of the pressure die axis (s) and speed of the collet axis (v) were used to counteract the wrinkles.

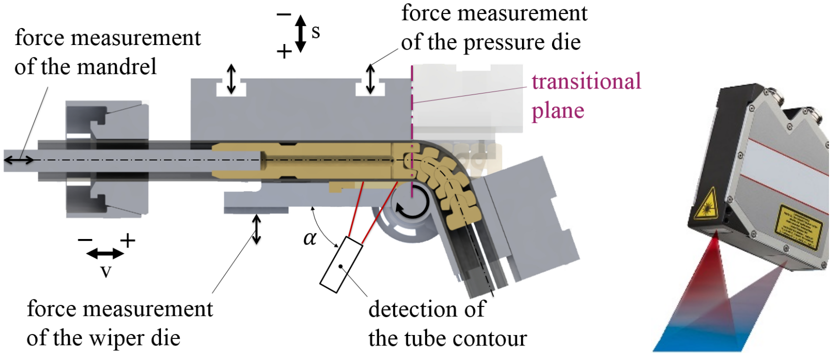

Figure 4.1: Experimental setup for measuring the wrinkles using laser line scanner and force sensors.

Fuzzy controller for wrinkle reduction

A fuzzy controller was developed that uses the pressure die and the collet unit to reduce wrinkles without requiring an operator to intervene in the process. The tools were set to avoid unnecessary high tool forces, but to generate only those needed to prevent wrinkles.

Fuzzy sets were created for three input variables and two output variables. Production rules established the link between the input and output variables in the form of a rule base. Based on characteristic diagrams, the fuzzy controller could be tested theoretically. In practical tests, the control was iteratively adapted and subsequently validated. Varying the wall thickness, the number of bends and the material, the bending results were evaluated using the wrinkle evaluation factor. Significant wrinkle reduction was achieved. Figure 4.2 shows the controlled travel of the pressure die.

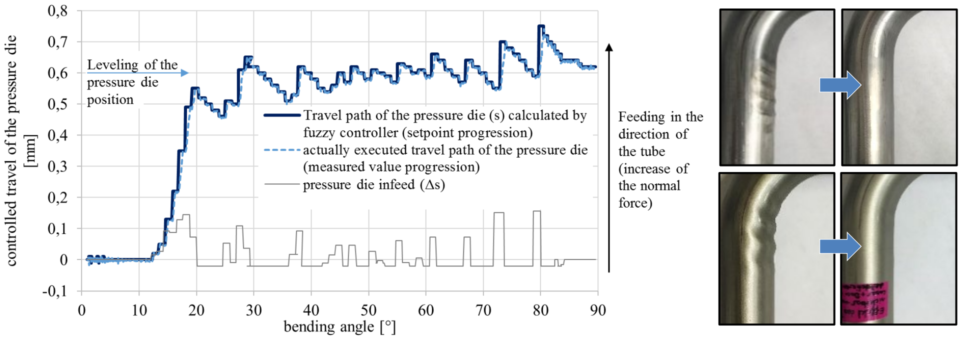

Figure 4.2: Controlled travel of the pressure die for wrinkle reduction, tube contours bent with and without fuzzy control.

The pressure die levels off at a suitable position and normal force. This can reduce wrinkling on the one hand and tool wear and the risk of cracking on the other.

Major publications on forming technology

Borchmann L., Schneider D., Engel B. Design of a fuzzy controller to prevent wrinkling during rotary draw bending. 24th International Conference on Material Forming, ESAFORM 2021 (accepted manuscript).

Borchmann L., Frohn-Sörensen P., Engel B. In situ detection and control of wrinkle formation during rotary draw bending. Procedia Manufacturing, Volume 50 (2020), Pages 589-596, ISSN 2351-9789, doi: 10.1016/j.promfg.2020.08.106.

Borchmann, L., Heftrich, C. & Engel, B. Influence of the stiffness of machine axes on the formation of wrinkles during rotary draw bending. SN Appl. Sci. 2, 1627 (2020). doi: 10.1007/s42452-020-03419-1.

Borchmann, L; Frohn, P.; Engel, B. Sensitivity analysis of the rotary draw bending process as a database of digital equipping support, SheMet 2019, doi: 10.1016/j.promfg.2019.02.100.

5. Furnanceless cyclic heating via induction (OTTER)

Contact: Jonas Reuter, M.Sc.

Motivation and aim

Direct and indirect press hardening are well established manufacturing processes, in particular for the production of highly stressed structural components in the automotive industry. The number of components produced with these techniques increase steadily. Commonly continuous furnaces (usually special machines) are used to heat up the circuit boards, resulting in drawbacks of large space and energy requirements. In addition to this, austenitising the circuit boards in the furnace for several minutes, is the cycle time-critical process step in the manufacturing process.

For this reason, the chair of forming technology (UTS) and the Automotive Centre Südwestfalen (ACS) are investigating the potential of inductive circuit board heating as an alternative to furnace heating in a collaborative project. The aim of the project is to define and create the conditions for the industrial use of this technology.

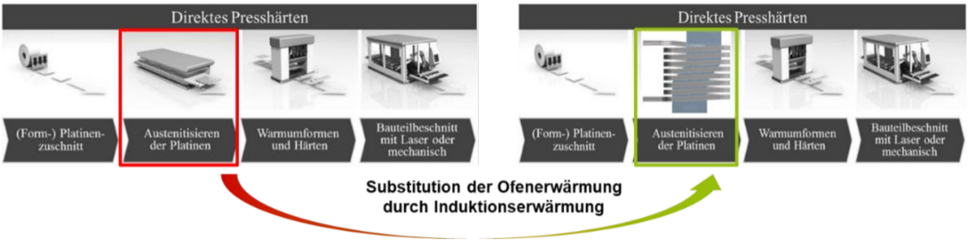

Figure 5.1: Induction board heating as an alternative to furnace heating, source: Dissertation T. Todzy (UTS)

The following questions should be researched, examined and answered in the scope of this project:

- What are the requirements (Inductor and generator geometry, coupling distance, magnetic field amplifier, etc.) for an induction furnace in order to include rapid and homogeneous heating of the boards?
- How does rapid induction heating affect the base material (structure, mechanical properties)?
- What influence does occur during rapid induction heating on the AlSi or Zn coating?
- Is it possible to achieve comparable component properties with fast induction heating in place of conventional furnace heating?

Procedure

In the first step, basic heating tests are carried out on a laboratory scale aiming for homogeneous heating of the circuit board to around 950 ° C (see Figure 5.2), required as a reference for building a resilient simulation model. In the next step, this simulation model is used to design the heating process for a sample component, whereupon this is produced in final press hardness tests.

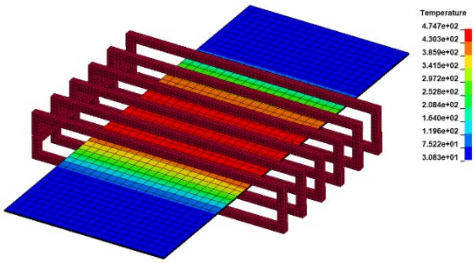

Figure 5.2: FE-simulation of induced heating via LS-Dyna

From the knowledge gained up to that point, a method for process design is derived, which is then used to prepare an inductive heating process - also with regard to partial circuit board heating - for a near-series component.

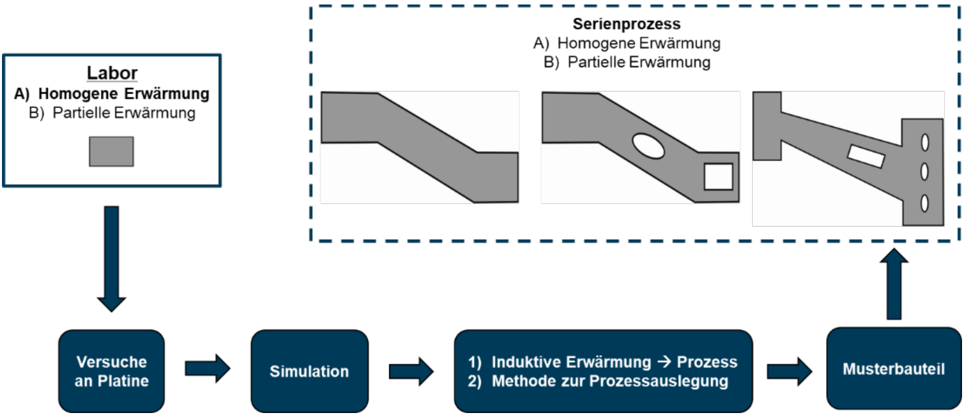

Figure 5.3: Process development approach

6. Circumferential forming of continuous reinforced thermoplastic tubes

Funding programme: ZIM

Funding code: ZF4358701RU6

Cooperation partner: Transfluid Maschinenbau GmbH

Editor: Jonas Reuter, M.Sc.

Motivation

Continuous fibre-reinforced thermoplastic tubes (CFRTT) are suitable for many lightweight applications including the usage as structural parts or pressure lines. In a former cooperation project (ZIM BiProFVR, funding code KF2019226EB3) a bending process for wounded CFRTT was developed in collaboration with the company *AFPT GmbH*. In functional tests the bent tubes withstood burst loads up to 1500 bar, but often showed a failure at the crimp connections at the tube ends in many tests at an early stage though.

Objective

For this reason, the aim of this project was a collaboration with the company *Transfluid Maschinenbau GmbH,* to develop a forming process, as well as the needed industrial equipment, to manufacture geometries at the tube ends (see Figure 6.1) enabling load applications through tight fits.

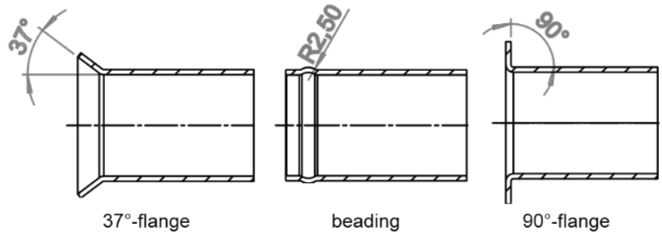

Figure 6.1: Target geometries

Forming Machine and Process

The forming process was setup on a tube-end forming machine from the machine manufacturer *Transfluid Maschinenbau GmbH* (see Figure 6.2). The so-called combination machine, including their seven tool positions, ensures the potential to implement a series of different axial and rolling forming operations for tube end forming.

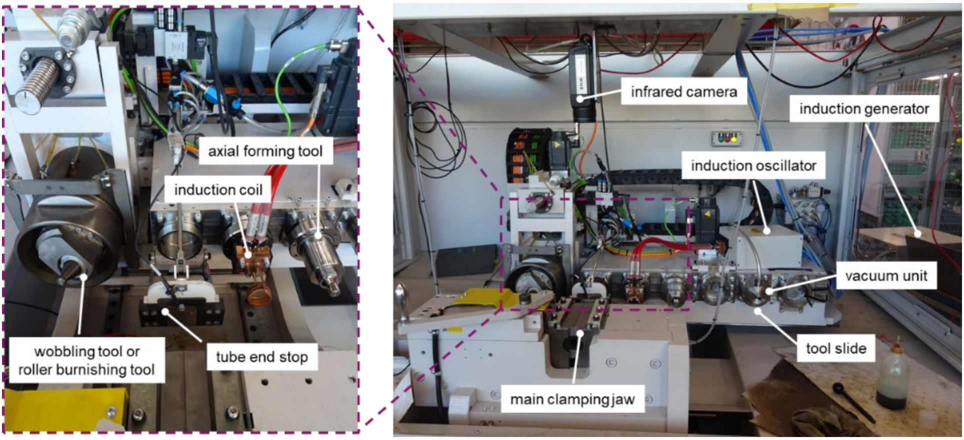

Figure 6.2: Setup of the forming machine

The setup in Figure 6.2 can be subdivided in three functional units, namely a clamping device, an inductive heating and a shape related forming unit. The clamping unit, consisting of a main clamping jaw and a tube end stop, is responsible for fixing the CFRTT in a defined position. To avoid damages on the tube through tool contact and to compensate variations of the outer tube diameter, the main clamping jaw has an elastomer inlay. For the first time, an induction unit was implemented for heating CFRTT. Contrary to other common heating technologies (hot gas, infrared, etc.), the main advantage of this method is the relatively high heating rate caused by heat generation in the material itself, which makes it very promising for industrial applications. Heating up the CFRTT up to or even above melting temperature of the thermoplastic matrix, is an essential requirement for the forming process. Due to the significant reduced viscosity of the matrix in the heated state, the forming mechanisms on the micro scale, such as sliding of fibre layers, could take place.

The forming unit consists on the one hand of the forming tools, and on the other hand of an intermediate clamping jaw (see Figure 6.3). During the heating process, the intermediate clamping jaw is open. Following this, the heated and freestanding tube end is enclosed to build up the cavity in the subsequent shape related forming process. If the deformation behaviour of the CFRTT makes it necessary, a temperature conditioning of the intermediate clamping jaw by heating cartridges can be realised.

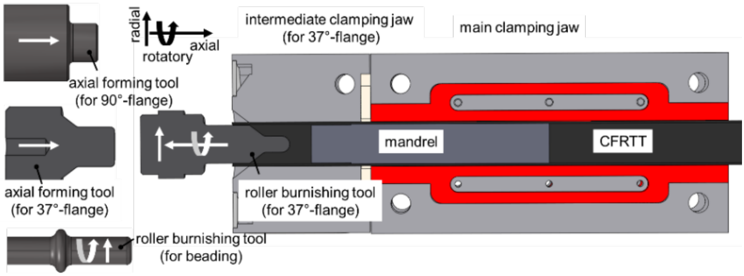

Figure 6.3: Tool concepts and tool kinematics for different forming operations

Based on established metallic tube end manufacturing processes, different tool concepts were further designed, tested and developed further (see Figure 6.3). For manufacturing the 37°-flanges, two operations are considered, a one-step axial as well as a rolling process. The beadings are manufactured by a rolling process. For manufacturing the 90°-flanges, the capability of a two-step process was investigated. In the first forming process step the tube end is widened by rolling method. In the second stage the widened tube end is heated up again and an axial forming tool redirects the material to final contour. All process variants have in common, hat a mandrel is placed inside the tube during the whole time, fulfilling two essential tasks. One task is to avoid a bending or even kinking of the tube during the heating process and to ensure the alignment of the tube consequently. Another task is the prevention of displacement of material into the tube interior due to the forming process.

During the whole process the travels as well as the speeds of the machine axis, the operating parameters of the induction heating system (current, voltage, power) and the temperature of the intermediate clamping jaw, measured by four Pt100 temperature sensors, are recorded. All the time synchronised measuring data can be exported via OPC-UA interface for further analysis and documentation. Simultaneously, an infrared camera monitors the tube temperature from the beginning of the heating process until the closing of the intermediate clamping jaw.

Results

The project successfully concluded with the development of a process and the required industrial equipment for CFRTT end-forming. For the first time, inductive heating was used in a forming process for CFRTT. The target geometries could be manufactured reproducible. Analyses of the manufactured parts, such as light microscopy of cross section polishes, geometry measurements or determination of fibre orientations, provide important data for research on forming mechanisms of CFRTT.

Figure 6.4: CFRTT with 37°-flange and hydraulic fitting

7. Detection of material defects in thermoplastics by means of active lockin thermography

Editor: Dipl.-Ing. Sonja Poleschke

Ensuring product quality is an integral part of industrial production. Either the component meets the quality requirements or the type, size and location of the defect lead to the selection of the part [1]. In the automotive sector, fiber-reinforced thermoplastics have established themselves as lightweight construction materials. A possible quality inspection of this material is the active lockin thermography. It belongs to the non-contact and non-destructive testing methods. It is based on the fact that material defects influence the heat diffusion process in an object and can thus be analyzed on the basis of the temporal course of the heat radiation at the object surface [1].

The **aim of this scientific work** is to determine the context between the defect type in glass fibre reinforced polypropylene and the image information from active lockin thermography.

The **principle of active lockin thermography** with two halogen lamps, computer, thermal imaging camera and material sample (Figure 7.1) is described in the following. Using intensity-modulated halogen lamps, the component surface to be tested is excited sinusoidally with electromagnetic waves over a longer period of time [1]. As a result, thermal waves propagate in the component. This causes the component temperature to vary. The excitation time depends on the excitation frequency and the number of measuring periods. If waves encounter a boundary, i.e. a local change of the effusivity, a certain proportion of them become reflected. The heat conduction in this area differs from that of the undamaged material. The superposition of temperature oscillation on surface with reflected thermal waves forms the wave field which is measured by the infrared camera at the sample surface. As a result of a thermographic investigation, a phase image is output which shows the time delay of a thermal response in correlation to the excitation at a specified frequency.

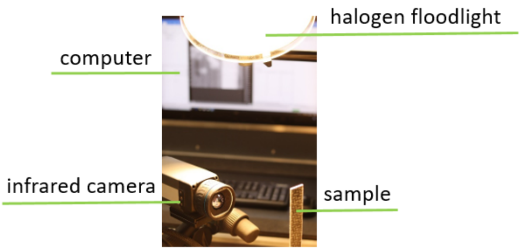

Figure 7.1 Test setup active lockin thermography

The phase image can contain information from component depths up to 6 mm.

The spectral separation of excitation and measurement is supported by two glass filters in front of the halogen lamps. They reduce the infrared component of the halogen radiation. Thus, the measured temperature is mainly composed of the infrared radiation emitted by the component. The test method works without calibration.

In this work, samples made of **endless glass fiber reinforced polypropylene** are examined by means of active lockin thermography. The material consists of three fabric layers and is 1.5 mm thick in total. The type of fabric is called twill weave. The weft and warp threads do not alternate evenly. Faultless and faulty samples are examined. Defect types introduced in a defined manner include fibre breakage, local and global fibre displacement, delamination and insufficient consolidation. Fibre breakage and fibre displacement are introduced in the top as well as in the middle fabric layer.

Two defect types are presented as examples of the results (Figure 7.2). The insufficient consolidation is visible on the left phase image as a bright area. Interrupted black lines show the fiber breakage on the right image.

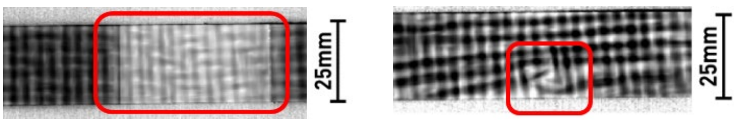

Figure 7.2 Types of defects of insufficient consolidation and fiber breakage

The **size and position of a fault** are important for its detection. The larger the defect is and the closer it is to the investigated surface, the easier it is to locate. Variations of excitation frequencies, number of measurement and settling periods and intensity modulation of the optical waves can contribute to more accurate and clearer defect representations on the phase images.

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8. Process development of Incremental Swivel Bending (ISB)

Responsible: Peter Frohn-Sörensen

Motivation

Due to their manufacturing flexibility, kinematic forming processes can meet industrial requirements for high adaptability of production with regard to individualization production on demand. The processes are characterized by tooling that is independent of the individual part geometry. The target geometry to be produced is therefore not determined by the shape of the tools, but by the configuration of the kinematic process parameters (Figure 8.1).

Figure 8.1: Manufacturing flexibility for profile bending. Various cross sections from AHSS, bent by the ISB process.

Due to the sequential production process, incremental forming processes offer the possibility of adapting the incremental step size to the material requirements depending on the geometry to be produced. The flexibility of production is further increased with incremental forming, since the design is generated by a relatively small forming zone, which may move several times over the workpiece.

Since the target geometry is not already defined by the shape of the tools (Figure 8.2), the process parameters of kinematic forming processes must be derived from the required geometrical and material-related properties of the target product and semi-finished product, respectively.

Figure 8.2: Research tool for profile bending using ISB. Open profile cross sections are supported on a segmented mandrel.

Process models have already been developed for various processes. For example, bending with 3- and 4-roller bending machines has been laid out analytically and also for the profile bending processes 3-roller bending and shear bending, knowledge about the interrelationships of kinematic and material- and geometry-related parameters is already available. For the incremental processes, knowledge is available above all for bulk forming - especially open-die forging.

These findings are usually described in the form of process models which can be validated by means of FE simulations and real experiments or model tests.

Objective

The aim is the description of a process model for incremental swivel bending to predict the kinematic process parameters for bending of a defined contour under consideration of the tribological and material-related influences. In the future, kinematic incremental bending processes based on frictional force transmission can be taken into consideration for the preliminary design of component geometries.

Methodology

Incremental swivel bending has already been tested as a flexible profile bending process using an industry-oriented demonstrator application (Figure 8.3).

Figure 8.3: Incremental profile bending (ISB) in two bending planes of a 120 x 90 mm hat shaped profile from dual phase steel.

However, previous findings are limited to empirical bending experiments and to finite element simulation based investigations. For incremental sheet metal bending processes based on the physical principle of frictional force transmission, no process models have been developed so far. When designing the incremental swivel bending process, it is therefore particularly important to describe the unlubricated friction state in an analytical process model. By modelling the forming zone of the frictionally engaged in-plane bending of sheet metal strips, the plasto-mechanical relationships when bending an increment are established. In addition, a description of the incremental superposition of several forming zones is developed. For the process design of the ISB, process windows for the bending increment and the segmented bending bend are derived. The modelling is validated in comparison with FE simulations and physical experiments.

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9. Flexible incremental bending of cones from sheet metal

Grant program: ZIM (AiF)
Grant No.: ZF4162306US7
Responsible: Peter Frohn-Sörensen

Motivation

Cones made of sheet metals have various applications, for example they are suitable as funnels for free-flowing materials, connectors between pipes with different diameters, furniture parts, covers or housings in apparatus and tank construction.

Conical sheet metal components can be manufactured using various metal forming processes. Deep drawing and spinning offer a high degree of manufacturing accuracy with comparatively simple process control, since the geometry to be produced is already stored in the form of a die. However, due to the geometry-related tooling of these processes, cone geometries cannot be varied, since distinct tool sets are required for individual cones. By roller bending, conical sheet metal components can be produced flexibly by variation of the process parameters. The radii are, however, bound to the diameter of the bending roll with regard to minimum feasible diameters. The swivel bending process can be used, with a sequential mode of operation, for highly flexible production of sheet metal cones (Figure 9.1).

On the swivel bending machine, the conically bent contours can be provided with additional geometric component features, such as sharp bending edges and folds, without the need for changing tools.

Figure 9.1: Flexibly bent cones from 3mm S235JR steel.

Since the use of shape-bound tools is not necessary, swivel bending can be used flexibly to produce geometrically variable cones. This manufacturing flexibility is generally attributed to kinematic forming processes in accordance with the technical guideline VDI 3430.

In contrast to roll forming, there are no process models for swivel bending to derive the required process parameters from target conical geometries. The swivel bending of conical sheet metal shells has so far been carried out in a try-out operation using a trial and material-intensive approach, in which the machine operator's experience plays a crucial role. The determination of the relevant sequential parameters of the alternating bending and feed steps was not possible until now.

In cooperation with the company Dr. Hochstrate Maschinenbau Umformtechnologien GmbH, the Chair of Forming Technology at the University of Siegen is developing a kinematic process model for swivel bending of geometrically defined cones, which is validated by finite element simulations (Figure 9.2) and bending experiments.

Methodological approach

Due to the circular unwinding of conical components, a rotary feeding kinematic results when swivel bending conical sheet metal parts: A sheet metal blank corresponding to the conical shell is fed to the machine with specially developed feeding kinematics. In contrast to the conventional linear movement of the feed units of swivel bending machines, the semi-finished sheet metal product is fed on a circular path. In addition, an inclined position of the swivel bending tools is an essential part of the process control, since a radius from small to large must be generated over the width of the machine in accordance with the upper or lower diameters of truncated cones. No fixed clamping devices are required during the process, as the machine feed continuously positions the sheet metal working piece. The cones can thus be manufactured in an uninterrupted production sequence of alternating bending and infeed without the need for reclamping. In this way, conical sheet metal shells can be produced up to a closing angle of approx. 270° before the upper beam of the machine is potentially wrapped. For completely closed cones (360° bending angle), the upper beam of the swivel bending machine, specially developed for cone bending, can be deflected (Figure 9.3).

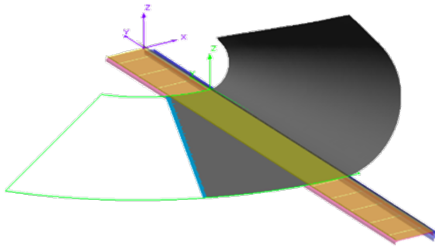

Figure 9.2: Finite element simulation model of sequential swivel bending of cones.

Figure 9.3: Newly developed swivel bending machine for bending of truncated cones from sheet metal with deflected upper beam.

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10. 3D-swivel-bending (SB³)

3D SCHWENKBIEGEN

Editor: Michael Schiller, M. Sc.

Introduction

Sustainable use of resources is of central importance in all sectors of industry, especially in manufacturing industries. Great importance is attached to the reduction of steadily increasing toxic emissions. Lightweight construction and the development of alternative drive technologies are topics of intense political, social and industrial debate.

Profile components are used in developments for car bodies and structural components, e.g. in the automotive and aerospace industries. For lightweight construction, this requires cross-sectional and load adaptation over the longitudinal axis of the profile components in order to meet geometric and functional requirements. The demand for several variations and decreasing quantities across all industries, challenge the manufacturing techniques in their main technologies. The market requirements in the automotive industry, next to other industries, are the individualisation of products, highly flexible (large-scale) mass production and the integration of business partners and customers. In the development of automotive electrification technologies, exist different concepts compared to conventional drive systems. This is accompanied by the fact, that comparatively smaller and therefore different batch sizes are produced.

To meet the demand on flexibility, both of these trends require production techniques. In the future, this can only be met economically by undergoing an extended design for the main technologies (forming processes). The requirements for manufacturing processes, especially for the forming processes, are low-tool production, fast set-up and quick product changes. In particular, scalability in terms of component geometry, machinable materials and batch sizes must be achieved in order to meet market requirements.

Process development

In order to enable the production technology of swivel bending to produce cross-sectionally variable and load-adapted profile components, the following main requirements for the process arise: Bending of non-linear bending edges, technically favourable design and manufacturing of the tools, low-tool production of profiles as well as fast set-up and quick product changeovers.

The established highly flexible swivel bending process is extended by 3D-swivel-bending in a way, that cross-sectional changes in the form of curved progressions can be introduced into the sheet metal, to be formed on longitudinally oriented components, e.g. profiles, already during profile production. For this purpose, the bending tools have a curved, also called non-linear, bending edge, which is complementary to the required edge of the component. This represents a significant technological advantage, since it allows the swivel bending process to produce profile components with adapted cross-sections and loads. The process and application limits of the established manufacturing method are thus significantly extended, as this has been limited to the manufacture of straight products or component edges so far. Compared to alternative profile manufacturing processes, 3D-swivel-bending is characterized by low machine and tooling costs, particularly low tooling requirements, short start- and set-up times and rapid product changes. With comparatively low financial outlay, this favours the production of small batches and creates greater production flexibility compared to variable semi-finished product and profile geometries. Thus 3D-swivel-bending offers the possibility to react flexibly to the market demand for variable products as well as adjustable, medium and smaller batch sizes and therefore higher performance compared to (established) reference technologies.

Compared to conventional swivel bending, 3D-swivel-bending typical results in plastic longitudinal and transverse strains in the sheet metal leg, see Figure 10.1.

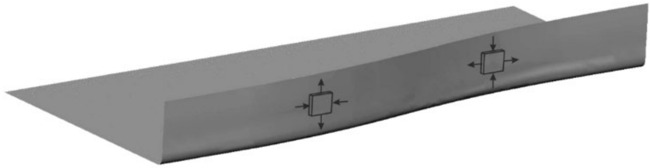

Figure 10.1 FE simulation - characteristic plastic longitudinal and transverse strains in the sheet metal leg of the s-shape

On the basis of initial preliminary tests, aiming for the principle consideration of feasibility, it was possible to bend a variable geometry along the cross-section in form of an s-shape with a simple and geometrically derived tool design, see Figure 10.2.

Figure 10.2 preliminary test - sheet metal forming (two views)

Acknowledgements

The research project 3D-swivel-bending (SB³) is funded by the European Union and of North-Rhine Westphalia (www.efre.nrw.de; www.wirtschaft.nrw.de).

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11. Remote Production

Editor: Michael Schiller, M. Sc.

Introduction

Analysing the market regarding the variety of industrial applications, the demand for individualised products in small batches, high flexible mass production and the integration of business partners and customers is rapidly increasing. With the development of intelligent manufacturing processes, the digital transformation enables smart processes, higher productivity and more efficiency in the commercial production. A production environment is aspired, where manufacturing plants are either self-operating or operated by intelligent processes. These so called ‘smart processes’ ensure the adaption of smart production processes for individual and individualised products. The potential of industry 4.0 offers the possibility of individualising products up to the time of set-up or, in the case of scalable manufacturing processes, even in the form of ‘lot size 1’.

Integration of the customer in the production process

For industrial processes, individualised production is only successful if typical delays, e.g. changes in geometry, can be significantly reduced. Despite simultaneous engineering when considering today's product development processes, breakpoints are necessary from which a new product development phase can take place.

If change in geometry occurs in a typical process, production must be aligned directly to new equipment, processes and quality assurance methods and tested afterwards. In a strict sense, the production of individual components under the demand of serial production requires a constant change, which consequently also means a recurring delay and a shutdown of the production line. In order to meet the labour, time and cost-intensive challenges, optimised processes, changes in manufacturing and production technology, as well as the integration of the customer in production technology are required. The process regulation through control, tool adjustment as the initial process step, sensor-actuator tool concepts and the development of scalable and flexible manufacturing processes must be monitored. As part of the research project, a process was developed that enables customers to be integrated into a smart production process. A customizable human ergonomic cantilever chair is used as a product example. It is made from semi-finished tube products using the flexible and scalable free-form bending manufacturing process. This process can be stated as hard customisation, where the individualisation is carried out in production. In addition to the production of an individualised product - production on demand - production is also carried out on request. The geometrical body dimension of the customer is recorded using a body scan that can be carried out from home, using the Kinect sensor bar or a smartphone app. The data generated by the customer, which serves as the basis for production, is transferred to a cloud and interpreted there. In a parameterised basic construction, an automatic construction machine ergonomically adjusts the cantilever chair to the previously recorded body dimensions, see Figure 11.1.

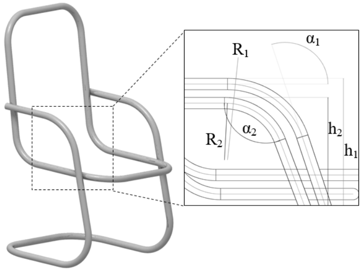

Figure 11.1 CAD-model cantilever chair

A CAD/CAM-module calculates the required process and machine data from the construction files. A generic bending program automatically creates and transforms the code for the computer-aided numerical control of the bending machine. The bending process starts automatically. In addition to this, an access from a semi-finished product database is possible to ensure the process control. From the scan process, followed by the data processing in the cloud until the actual production process starts, it takes just a few seconds, see Figure 11.2.

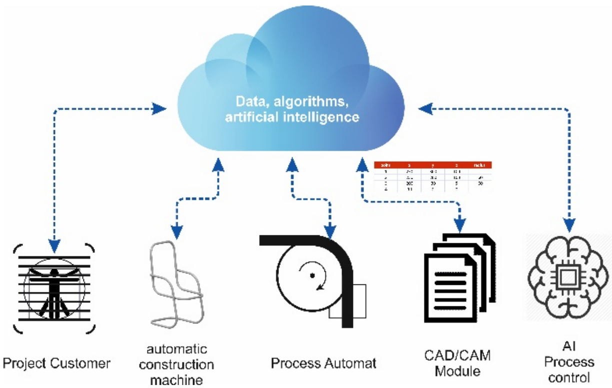

Figure 11.2 Process scheme remote production

Outlook

Lab tours are offered in the demonstration factory of the chair of forming technology, where technical possibilities, which arises with the digitalisation, are presented. The employees of Mittelstand 4.0 competence centre Siegen supporting small and medium enterprises (SME's) in Southwestfalia and beyond with questions and issues in digitalisation. One of the key points is to qualify and involve the employees in the digitalisation process.

Further information about the competence centre: www.kompetenzzentrum-siegen.digital

12. Forming simulation of fabric-reinforced thermoplastic parts

Introduction

Fiber reinforced thermoplastic parts are used for automotive lightweight parts. After heating over their melting temperature, they can be formed with stamp forming processes. Their mechanical properties after the forming process are influenced by present fiber angles and wrinkles. Thus, the aim of this work is the prediction of fiber angles and wrinkling during and after the forming process with FEM analyses.

Fabric reinforced polyamides are modelled with Abaqus/Explicit. The shear, tensile, compression and bending behavior is measured with different material tests in a thermal chamber at forming temperature. There is currently no standardization for these tests. The material model is validated using these material tests as well as demonstrator component that is formed with an industry-oriented process. Fiber angles and wrinkles of the component are measured and compared to FEM results. Sensitivity analyses of FEM models should give an estimation about the influence of input parameters to FEM results and their interactions.

FE analyses with Abaqus/Explicit

The FEM-model consists of different elements that are arranged in parallel to decouple the different stiffness of the fiber reinforced thermoplastic. The shear, bending and tensile stiffness values have very different orders of magnitude. Thus, different 1D and 2D elements are combined to a unit cell, consisting of beam, shell or membrane elements for example (cp. Figure 12.1). The blank can be modelled from a large number of unit cells.

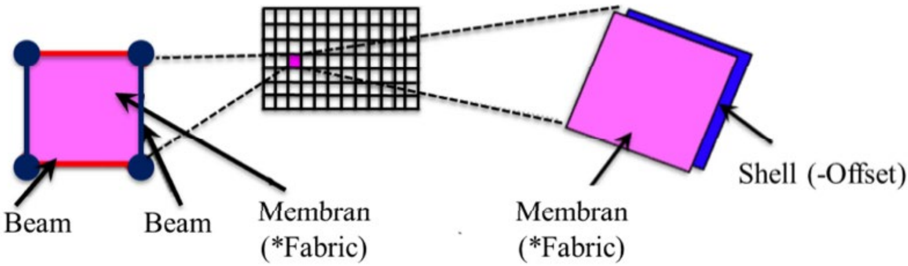

Figure 12.1: Unit cell Beam-Membrane and Membrane-Shell

The unit cells in Figure 12.1 are selected for FE analyses in this work and will be compared based on FE results of material tests and forming analyses of the demonstrator component. The beam-membrane model has the advantage that the anisotropy of the fabric is already given by the arrangement of the beam elements. The membrane-shell model has the advantage of a smaller number of elements.

The FE models just consists of elements and material cards from Abaqus/Explicit to make it easy for all users to simulate with this model without having to program your own. The model bases on membrane elements and the material card *Fabric.

Material characterization

Another research object is the (further) development of material tests for the characterization of stiffness behavior above the melting range of the thermoplastic material that is necessary for its formability. The forming mechanisms fabric shear and interply slip just can occur if the thermoplastic matrix is molten. Fabric shear means the change in angle between several fiber bundles. Its value is about 90° at the beginning. Interply slip means the individual fabric layers slide against each other to compensate the difference between inner and outer radii at a bending load, for example.

The test method that are described in the literature are often derived from methods for dry fabrics that are not impregnated with thermoplastic. Thus, they have to be modified for the usage with molten thermoplastic matrices which means lower coefficients of friction in clamping areas or unwanted adherence to metal parts. There are no standardized methods for characterization of fiber reinforced thermoplastics above their melting temperature. The aim of this work is also the definition of a test specification.

Therefore, different cantilever-bending-tests, shear tests (Picture-Frame and Bias-Extension-Test) and friction tests (Pull-out and Pull-through) will be investigated and compared. Latter ones are used to characterize the tool-ply and the ply-ply friction behavior. Figure 12.2 shows an example of a bias-extension-test for shear characterization and the calculation of shear angle values with Matlab.

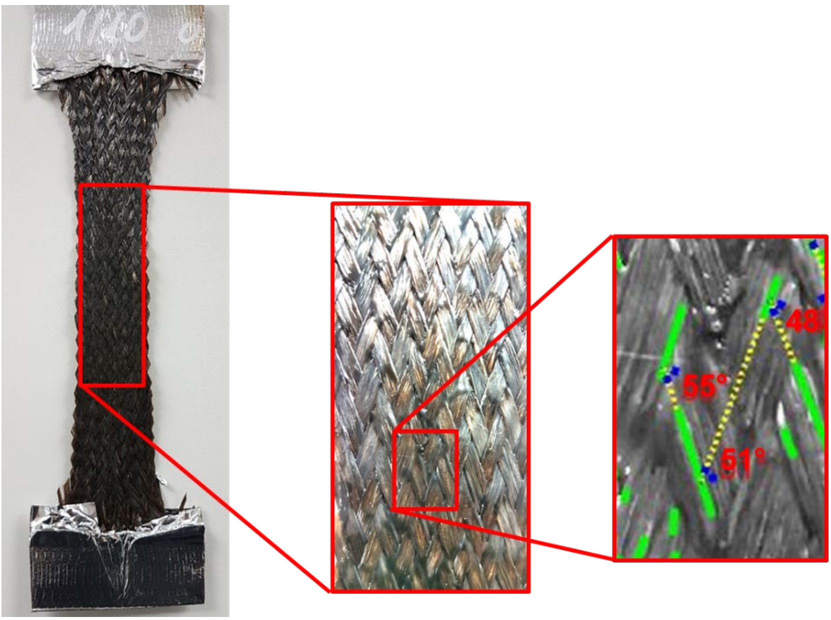

Figure 12.2: Bias-Extension-Test (left) and detection of fiber angles (right)

Demontrator component and validation

Figure 12.3 shows the demonstrator component that is used for validation of FEM-model and firs FE results. The organic sheet is clamped into a frame and heated up to the forming temperature with an infrared heating unit. Afterwards it is transferred to an industrial press by a robot. Afterwards the wrinkles will be measured with a laser scanner and fiber angles will be calculated with Matlab.

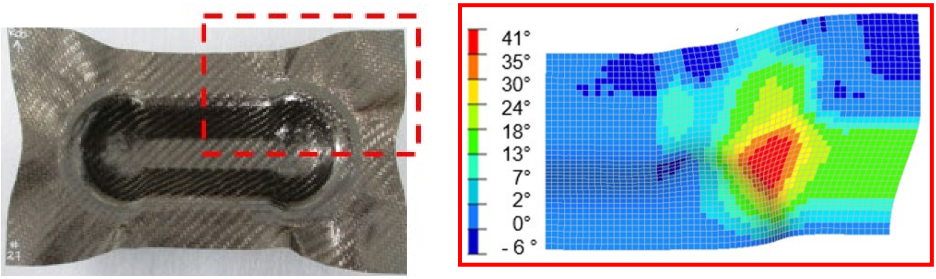

Figure 12.3: Demonstrator component (left); Simulation of fiber angles (right)

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13. Bending of profiles with variable cross-section

Editor: Daniel Nebeling

Das Projekt AMALFI wird im Rahmen von COMET –Competence Centers for Excellent Technologies durch BMVIT, BMDW, [Oberösterreich] gefördert. Das Programm COMET wird durch die FFG abgewickelt.
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Introduction

Currently, both open and closed profiles with a constant cross-section are free-form bent. However, roll forming can also be used to produce profiles with a cross-section that varies along the longitudinal axis [1]. A manufacturing process, where these variable profiles can be bent, is still missing. Within the framework of the AMALFI research project, the University of Siegen is working on the research and development of appropriate process extensions. With a bending process like this, the possibilities of lightweight design for structural components are significantly expanded. There are applications for profile bending structures, for example in the furniture industry, in commercial vehicle construction or in the automotive industry. Further weight savings would be possible by a load-adapted design.

State of the art

The semi-finished products, that will be bent in this project, are roll-formed components. Roll forming is one of the most common manufacturing processes for the production of open and closed profiles. The roll forming of structural components with cross-sections, that vary along the longitudinal axis, have already made it possible to achieve lightweight design for straight sections [1].

Three-roll push bending (DRSB) is a free-form bending process, suitable for open and closed profiles with relatively large bending factors. The tools for DRSB must be adapted to the cross-sectional geometry of the profile. A typical tool set consists of a bending roller, a forming roller and two to three support rollers. In the DRSB, the bending is generated kinematically by the infeed of the forming roll. This means that the same tool set can be used for different bending radii [2].

Challenges

One of the challenges in this research project is the springback of the profile. After unloading, the profile will spring back differently depending on the current profile cross-section. Therefore, it is necessary to investigate the production accuracy for the nominal bending radius, especially in the transition areas of two different cross-sections. An additional challenge is the torsion of the profile cross-section. In the current investigated Z-sections, the transverse force, required for bending, is not introduced at the shear center, which inevitably leads to torsion of the cross-section [3].

Tool concept

In order to be able to bend profiles with a variable cross-section along the longitudinal axis, it is necessary to extend an existing free-form bending process in a way, that the tool positions can be adapted to the profile cross-section during the bending process. Within the scope of this project, the DRSB was applied on a rotary draw bending machine of the Department of Forming Technology at the University of Siegen. The actual tool design is shown in Figure 13.1. In addition to the standard tool elements like a bending and forming roll as well as the support rolls, further support elements are used. These should prevent deformation of the profile cross-section during the bending process. Due to the fact, that a position change of the bending roller on the machine is not possible during the bending process, a position adjustment for the remaining tools has to be proceed along the profile contour.

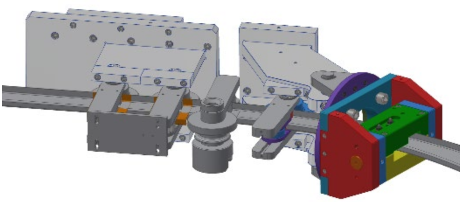

Figure 13.1: Tool concept for bending the profiles

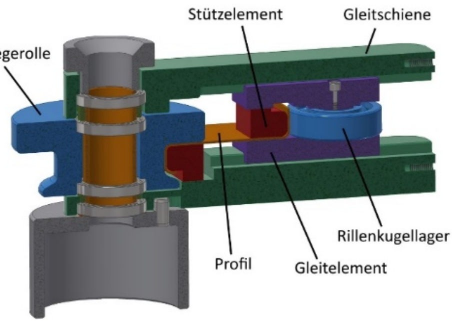

Figure 13.2: Design of the bending roller

Figure 13.2 shows the design of the bending roller with the associated support elements. At the inner radius, the profile is supported by the contact area of the bending roller and on the inside by an additional support element made of a structural plastic. On the outer radius, the profile is supported contact area by a ball-bearing and also on the inside by a support element made of plastic. Both, the bearing and the support element for the outer radius, are mounted on a sliding element. The sliding element can move freely within a guide perpendicular to the profile longitudinal axis. Within the sliding element, the profile runs between the support element and the deep groove ball-bearing. Thus, the position of the sliding element adapts to the current profile cross-section. Active movement of the sliding element is not required.

There are already several concepts for the superposition of torsional stress during bending. Groth has shown in a work, that even non-symmetrical profiles can be bent flat by a specific superposition of torsion [3]. Additionally, the Torque Superposed Spatial (TSS) bending process allows a targeted torsion to be introduced into the profile [4].In the current process, a torsion should only be superimposed on the profile after the actual bending process though.

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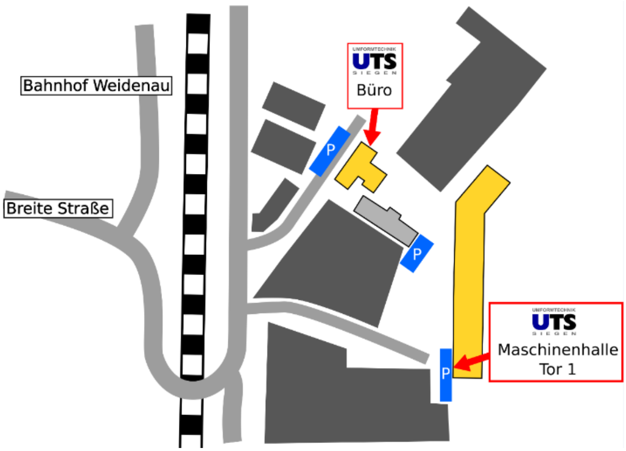

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