Sheet Metal Forming I

Simulation Techniques in Manufacturing Technology

Lecture 3

Laboratory for Machine Tools and Production Engineering
Chair of Manufacturing Technology

Prof. Dr.-Ing. Dr.-Ing. E.h. Dr. h.c. Dr. h.c. F. Klocke
Outline

1 Introduction

2 Sheet Material

3 Sheet Metal Forming Techniques
   3.1 Deep Drawing Process
   3.2 Ironing Process
   3.3 Bending Process
   3.4 Stretch Forming Process
   3.5 Spinning Process
   3.6 Hydroforming
Introduction

Methods of Forming – Classification DIN 8580 ff

Manufacturing processes

- Casting
- Forming
- Cutting
- Joining
- Coating
- Changing of material properties

Compressive forming
- Open die forging
- Closed die forging
- Cold extrusion
- Rod extrusion
- Rolling
- Upsetting
- Hobbing
- Thread rolling

Tension compressive forming
- Deep drawing
- Ironing
- Spinning
- Hydroforming
- Wire drawing
- Pipe drawing
- Collar forming

Tensil forming
- Stretch forming
- Extending
- Expending
- Embossing

Bending
- Translate
- Twist
- Intersperse
- With linear tool movement
- With rotatory tool movement

Shear forming
- Shearing
- Fine Blanking
- Cutting with a single blade
- Cutting with two approaching blades
- Splitting
- Tearing

severing

With linear tool movement

With rotatory tool movement

Translate

Twist

Intersperse

Shearing

Fine Blanking

Cutting with a single blade

Cutting with two approaching blades

Splitting

Tearing

© WZL/Fraunhofer IPT
### Techniques of Metal Forming: Bulk Forming – Sheet Metal Forming

<table>
<thead>
<tr>
<th>Bulk forming:</th>
<th>Sheet metal forming:</th>
</tr>
</thead>
<tbody>
<tr>
<td>High changes in diameter and dimensions</td>
<td>No or low unwanted changes of the original wall thickness</td>
</tr>
<tr>
<td>High deformation</td>
<td>Lower deformation</td>
</tr>
<tr>
<td>High material hardening</td>
<td>Lower material hardening</td>
</tr>
<tr>
<td>High forces</td>
<td>Lower forces</td>
</tr>
<tr>
<td>High tool stresses</td>
<td><strong>than in bulk forming</strong></td>
</tr>
</tbody>
</table>

© WZL/Fraunhofer IPT
Outline

1 Introduction

2 Sheet Material

3 Sheet Metal Forming Techniques
   3.1 Deep Drawing Process
   3.2 Ironing Process
   3.3 Bending Process
   3.4 Stretch Forming Process
   3.5 Spinning Process
   3.6 Hydroforming
Sheet Material

Difference Between Sheet Material and Bulk Material

- **sheet**
  coil (width, length » thickness)

- **bulk**
  slab (460 x 1400 x 3400)
Coil velocity is considerably higher than slab velocity

\( v_1 \approx 400 \ v_0 \rightarrow l_1 \gg l_0 \)

The lengthwise extension of the sheet leads to directionally dependent material properties.
The term ‘anisotropy’ describes:
The material properties’ dependence on the orientation to the rolling direction.

In sheet metal processing:
- perpendicular anisotropy \( r \) (depending on sheet thickness) and
- plane anisotropy \( \Delta r \) (depending on sheet plane) are encountered.

Anisotropy has to be considered in the dimensioning of forming processes.
Sheet Material

Forming Property: Measuring Grid Technique

- Deformation of the measuring grid because of tensile and compression stresses inside the sheet metal while forming

- The effective strain can be derived from the grid deformation = maximum deformation (forming limit)

\[ \phi_b = \ln \frac{b_1}{d_0} \quad \phi_l = \ln \frac{l_1}{d_0} \]
Sheet Material

Forming Property: Forming Limit Curve

Variable strip thickness to vary $\varphi_2$ (one test corresponds with one value of $\varphi_2$)

- Determination of forming limit curve to predict failure by using FEM
Sheet Material

Delivery Possibilities for Sheet

- Hot rolled strip
  - thin sheet
  - thick plate
- Cold rolled strip
  - thin sheet
  - thick plate
- Surface finished sheet
- Tailored blanks
Sheet Material

Development of High Strength Sheet Materials

- Elongation at Fracture $A_{80}$ / %
- Tensile Strength $R_m$ / MPa

Materials:
- IF
- DC01-06
- ZStE-BH
- TRIP / RA-K
- Al-Leg.
- Mg-Leg.
- ZStE-TM / QStE-TM
- CP-W
- MS-W
- TWIP 25% Mn / TRIP 15% Mn
- Corrosion resistant austenitic steels

© WZL/Fraunhofer IPT
Coil material can be made of sheets differing in thickness and strength. Ulterior motive is the production of sheet components with differing sheet thickness considering feasible loadings.
Outline

1 Introduction

2 Sheet Material

3 Sheet Metal Forming Techniques
   3.1 Deep Drawing Process
   3.2 Ironing Process
   3.3 Bending Process
   3.4 Stretch Forming Process
   3.5 Spinning Process
   3.6 Hydroforming
Sheet Metal Forming

Deep Drawing

Deep drawing

Stretch forming

Spinning

Ironing

Bending

Hydroforming
Deep Drawing Process

Deep Drawing of a Plane Round Sheet Plate

- Punch
- Blank holder
- Sheet metal
- Drawing die
Deep Drawing Process

Material Flow – from Flange to Cup Wall

- Material displacement in circumferential direction causes **tangential compressive stresses** in the flange region.

\[
\begin{align*}
\text{a} &= \text{Material to be bent} \\
\text{b} &= \text{Material to be displaced}
\end{align*}
\]
Deep Drawing Process

Problem: Formation of Wrinkles in the Flange

- By exceeding buckling instability of the sheet material, the tangential compressive stresses produce wrinkles in the flange.
Deep Drawing Process

Failures in Deep Drawing

Earing
\(\Rightarrow\) Plane anisotropy

Eccentric position of circular blank
\(\Rightarrow\) Mistake of user

Cup base fracture
\(\Rightarrow\) Exceeding of tensile strength of the material

Lip formation
\(\Rightarrow\) Increased strain hardening of the material in edge region
Deep Drawing Process

Redrawing (Multi-Station Die)

- Production of rotationally symmetrical components by redrawing to reduce loadings on tools and workpiece
Use of brake or drawing beads to manage the material flow during drawing
Avoidance of buckling during the forming of asymmetrical components by the use of symmetrical geometry arrangement
Deep Drawing Process

Deep Drawing of Car Body Components

Quelle: Daimler
The application of a rubber pad or a membrane, which is filled with a liquid medium, is universal.
The process limits of deep drawing with rigid dies can be enlarged or circumvented.
Outline

1 Introduction

2 Sheet Material

3 Sheet Metal Forming Techniques
   3.1 Deep Drawing Process
   3.2 Ironing Process
   3.3 Bending Process
   3.4 Stretch Forming Process
   3.5 Spinning Process
   3.6 Hydroforming
Sheet Metal Forming

Ironing

Strech forming
Spinning

Ironing
Deep drawing
Bending
Hydroforming
Ironing Process

Schematical Description of Ironing

Sheet forming = Production of plane hollow bodies **without** required change of wall thickness

- Ironing = *Bulk forming*

- Ironing is applied for a defined reduction of the wall thickness of a deep drawn workpiece
Ironing Process

Multi-stage Ironing – Influence of workpiece velocity

- Achievement of high wall thickness proportions by multi-station ironing
- Because of the difference in velocity between intake and runout, the workpiece should have left the first ironing die before running into the next

![Diagram of ironing process](image)
Ironing Process

Progression of Force for Different Distances of Ironing Dies

- Low distance between ironing dies:
  - Increase of resulting force in triple drawing,
  - Risk of cup base fracture.

- Large distance between ironing dies:
  - Decrease of resulting force in triple drawing,
  - Large stroke of punch required.
High strains can be reached by the use of several ironing steps
Outline

1. Introduction
2. Sheet Material
3. Sheet Metal Forming Techniques
   3.1 Deep Drawing Process
   3.2 Ironing Process
   3.3 Bending Process
   3.4 Stretch Forming Process
   3.5 Spinning Process
   3.6 Hydroforming
Sheet Metal Forming

Bending Process

- Bending
- Stretch forming
- Spinning
- Deep drawing
- Ironing
- Hydroforming
Bending Process

Classification of Bending Techniques

Forming by bending

Forming by bending with linear tool movement

- Open bending
  - Straightening
  - Open circular b.
    - B. without radial stress
- Die bending
  - Radial die forming
  - Die flanging
  - Radial die forming
- Drawing by a sliding action
- Edge rolling
  - Winding
- Bending by bulging
  - Crimping
  - Roll straightening
  - Corrugating
  - Roll forming to shape
  - Roll draw bending
- Coiling
  - Swing-folding
- Rotary bending
  - Circular bending
  - Roll bending

Forming by bending with rotatory tool movement
Bending Process

Distribution of Stresses and Strain during Bending

- **$\varepsilon_{el}$**: Elastic elongation
- **$\varepsilon_{pl}$**: Plastic elongation
- **$\varepsilon_{bl}$**: Permanent elongation after springback

Neutral fiber

State of stress under load

State of stress after springback

Ideal plastic material
Bending Process

The Springback Issue

- Residual stresses of component lead to springback
- The state of residual stresses after forming depends on the reaction of the material deformation
- The flow behaviour at load inversion depends on history of deformation (Bauschinger-Effect)
Bending Process

Deformation in Bending Zone

- Reduction of cross section and deformation along the bending edge occurs when having thick sheets and small bending radii.

Especially in case of open bending.
Bending Process

Roll Forming to Shape

- Strips of optional length can be formed
Bending Process

Examples of Operation Steps using Die Bending

1. and 2. Step
3. and 4. Step
5. and 6. Step
7. Step

1. Step
2. Step
3. Step
4. Step
Roll bending is mainly used for rolling of thin, medium and thick plates for producing tubes and tubular workpieces. By variation of roll position non-rotationally symmetric workpieces can be produced as well.
Outline

1. Introduction
2. Sheet Material
3. Sheet Metal Forming Techniques
   3.1 Deep Drawing Process
   3.2 Ironing Process
   3.3 Bending Process
   3.4 Stretch Forming Process
   3.5 Spinning Process
   3.6 Hydroforming
Sheet Metal Forming

**Stretch Forming**

- Stretch forming
- Bending
- Spinning
- Deep drawing
- Ironing
- Hydroforming
Stretch Forming Process

**Difference Between Bending and Stretch Forming: The Neutral Fiber**

- Neutral fiber
- Stretched zone
- Upset zone
- Sheet thickness

**Open bended profile**

**Stretch formed profile**

- Reduction of springback by stretch forming
- Neutral Fiber (outside of the sheet)
Stretch Forming Process

Sketch of a Stretch Forming Press

- Low tool and machine costs concerning the size of the workpieces being produced
Stretch Forming Process

Stretch Forming Failures

- Cracks near to collet chucks
- Cracks in vertex region

Constriction with following crack
Brittle fracture
Stretch Forming Process

Stretch Forming Techniques

Basic stretch forming (high amount of waste material)

Tangential stretch forming (low amount of waste material)

Tangential stretch forming (underdrawing possible, higher process flexibility)
Real drawing of a car body panel is always a combination between stretch forming and deep drawing.
Outline

1 Introduction
2 Sheet Material
3 Sheet Metal Forming Techniques
   3.1 Deep Drawing Process
   3.2 Ironing Process
   3.3 Bending Process
   3.4 Stretch Forming Process
   3.5 Spinning Process
   3.6 Hydroforming
Sheet Metal Forming

**Spinning**

- Bending
- Stretch forming
- Deep drawing
- Ironing
- Hydroforming
Spinning Process

Spinning Process (Sketch) with Intermediate Stages

- \( s_0 \): Sheet thickness of circular blank
- \( d_0 \): Diameter of circular blank
- 0: Basic shape
- 1-6: Intermediate stages
- 7: Final stage

- Low tool costs and cycle times in comparison to alternative processes
Spinning Techniques

- **Counter tool**
- **Spinning roll**

**Contracting by spinning**

**Expanding by spinning**

**Spinning of inside beads**

**Spinning of external flanges**

**Necking by spinning**

**Spinning of external flanges**

**Thread spinning**
Spinning Process

Ironing by Spinning in Same and Opposite Direction

Same direction process
Flow of material in direction of tool movement

Opposite direction process
Flow of material in opposite direction of tool movement
Spinning Process

Defects in Production when Spinning a Cup

- Radial cracks by tangential compression and bending stresses
- Formation of wrinkles by tangential compression and bending stresses
- Tangential cracks by radial or axial tensile stresses
- Radial cracks by tangential tensile stresses

During spinning axial and radial tensile stresses occur as well as tensile and compressive stresses in tangential direction. These stresses can finally lead to an overload of the workpiece.
Maximum Accepted Spinning Proportion

Material St 13
d_{W}/d_{1} = 1.5

Related sheet thickness \( s_{0}/d_{1} \)
Spinning Process

Force Components at Spinning Process

- $F_a$ = Axial force
- $F_r$ = Radial force
- $F_t$ = Tangential force
**Spinning Process**

**Axial und Radial Force at Spinning Process**

- $d_W / d_1 = 1.2$
- $\rho_W / d_1 = 0.1$
- $\rho_W / d_1 = 0.2$
- $f / d_1 = 0.17 \cdot 10^{-2}$

Material St 13

Diameter after conditioning $d_1$

Diameter of spinning roll $d_W$

Curvature of roll $\rho_W$

Feed $f$

- Forming forces increase when feed and initial sheet thickness are increased.
- Axial and radial forces are influenced by spinning proportion $\beta$ and curvature radius $\rho_W$ of spinning roll without reduction of sheet thickness.
Spinning Process

Spinning Process by Manual Work

Source: MetalSpinners
Spinning Process

Roll Spinning Pulley

Source: Leico
Spinning Process

Components

Aluminium reflectors

Rocket tank bottom

Aluminium-car-rim

Source: Leifeld
Spinning Process

**Laser Aided Spinning**

Machine Set-Up

Process

- Increase of forming limit because of local heat input
### Outline

1. **Introduction**
2. **Sheet Material**
3. **Sheet Metal Forming Techniques**
   3.1 Deep Drawing Process
   3.2 Ironing Process
   3.3 Bending Process
   3.4 Stretch Forming Process
   3.5 Spinning Process
   3.6 Hydroforming
Sheet Metal Forming

Hydroforming

- Stretch forming
- Spinning
- Deep drawing
- Ironing
- Bending
Hydroforming

Principles of Hydroforming

- Initiation of process
- End of process

Expanding in a closed tool

No external pressure supply
Hydroforming

Production of a T-Part

Close press

Fill up with fluid medium

Move horizontal cylinder, adjust water pressure, direct counterholder

Open press, eject part

Counterholder
Tube
Halves of formtool
Seal stamp
Secondary form
T-part
Hydroforming

Production of a Engine Bracket

Hydroforming tool

Engine bracket with add-on parts

In comparison to conventional construction:

- 30 % lower weight,
- 20 % lower costs,
- 60 % lower tool costs.
Hydroforming
Production of a Engine Bracket

- Axial cylinders seal ends of tubes
- Preformed piece is flooded by hydromedium
- Forming with internal pressure of 1.500 bar
- Final shape of workpiece depends on die cavity
- Axial cylinders add material by sliding
- Punching after forming; slugs are bend down inside
Hydroforming

Examples of Components in the Field of Car Body

- Audi A6
  - Closure pipe
  - Main pipe
  - Control arm
  - Roof frame lateral l./r.
  - Transversal bar of windscreen
  - Rear bottom transversal bar
  - Sillboard l./r.
  - Transversal bar of seat l./r.
  - Reinforcement eaves gutter l./r.

- Audi TT

Production of high strength life and weight optimized components and units