Process adapted Dual Phase Steels
IRTG 1627 - A.2

Manufacture parts with adapted phases by using a modified process of press hardening

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Introduction - application and characteristics of DP steel

Aims of the automotive industry

- Passenger safety
- Lightweight body construction
- Low material costs

- DP steels are used in front and rear impact zones because of their high absorption of energy [ruukki, Stahl u. Eisen, 6/2013]

Preferred features are

- High energy absorption capability
  - Large uniform and total elongation $A$ in the tensile test
  - High ultimate tensile strength

Longitudinal members in car bodies (DP600) [Suwanpinij, P. 2012]
**Microstructure**

- DP steels are characterized by a microstructure of a soft ferrite matrix with hard martensite islands at the grain boundaries.
- Volume fraction of martensite or martensite with small islands of retained austenite is about 15% to 30%.
- This phase composition gives high strength and workability.
- Usage especially for deep-drawing processes (cold forming):
  - Anisotropic component behaviour
  - Reduced residual elongation / plastic deformation reserve in case of a crash.


Colour etching after Klemm
- F: 73%
- M: 22%
- RA: 5%

Microstructure of the DP steel DP600® [IW]
State of the art
2 methods for the production of dual phase steel

a) Specific cooling path subsequently to hot rolling

b) Continuous annealing in the intercritical temperature range $A_{c1} < T < A_{c3}$ after cold rolling

- temperature and time in the dual phase region are two important parameters in the intercritically annealing process
- ratio between ferrite and martensite can be adjusted by the soaking time and temperature

Manufacturing of DP steels (schematic)
(a) production of hot-rolled strip
(b) cold-rolled strip production
γ-austenite, α-ferrite, α'-martensite [Berns, H. et al. 2008]
Problem definition and motivation

Alternative process to manufacture DP steel components

I. Adjustment of an ideal mixed microstructure and component production by hot forming and tool cooling

Aim: good balance between high strength and ductility

- Utilization of the intercritical annealing temperature for sheet forming

Heat treatment in the two-phase region (A+F) with subsequent quenching [Roos, E.; Maile, K. 2008]
Problem definition and motivation

Alternative process to manufacture DP steel components

II. Manufacturing of dual-phase-steels by complete austenization and subsequent quenching due to a locally interstitial free microstructure

- Manufacturing of DP steel from annealing temperatures above \(\text{Ac}_3\)
- Simultaneous formation of ferrite and martensite from austenite
- Carbon is bonded in chromium carbides locally, therefore martensite transforms only partially
- Air hardening steel LH800®

Undissolved carbides in LH800® after austenitization at 1000 °C and 10 s holding time. Etchant: 2 % HNO\(_3\) (SEM picture) [Schaper, M. 2013]
Problem definition and motivation

Heat-treatment processes using the example of boron-manganese steel

- Part properties:
  - High strength (about 1500 MPa)
  - Small elongation at fracture (about 5 %)
- Press hardening parts applied as A- and B-pillars reinforcements (anti-intrusion parts) [ruukki, Stahl u. Eisen 6/2013]

Press hardening with following tempering

- Additional process step required
- Time-consuming tempering process

Stress-strain diagram of press hardened 22MnB5 [Krauss, G.; et al. 2008]
Problem definition and motivation

Heat-treatment processes using the example of boron-manganese steel

Planned process chain with annealing in the intercritical temperature range and subsequent quenching in a die

- Adjustment of the ferrite to martensite ratio
- Greater plastic deformation compared with cold forming
- Little or no anisotropy
- Greater plastic deformation reserve in case of crash
Problem definition

Identification of suitable parameters for annealing process

WP1: Experimental data collection

WP2: Modelling of the heating process
   - Fraction of austenite
   - Grain size evolution
   - Locally carbon distribution (if required)

WP3: Microstructure evolution during cooling process
   - Diffusionsless and diffusion phase transformations

WP4: Combination of cooling and forming operation
   - Microstructure evolution in dependence of the forming operation

WP5: Tempering
   - Change in hardness, bake hardening effect

WP6: Modell verification by comparison with the microstructure and the hardness

CCT diagram for 22MnB5. Austenitizing temperature 950 °C, forming temperature 800 °C

Effect of deformation before cooling, deformation CCT diagram for 22MnB5 [Schaper, M. et al. 2010]
Experimental investigations

Variation of the time-temperature profile

- Manufacturing of dual phase steel / multiphase steel

- Annealing in the intercritical temperature range
- Cooling
  - By immersion cooling
  - In a flat die (without forming)
  - In a contoured die (with forming operation)
- Identification of suitable process parameters

Variation of the annealing temperature

Variation of the cooling rate

Additional tempering

Interrupted hardening bainite formation

Generated microstructure
Experimental investigations

Variation of the time-temperature profile

- Manufacturing of dual phase steel / multiphase steel

- Austenitization
- Quenching ➔ Full martensitic hardening
- Intercritical annealing
- 2nd quenching

- Homogeneous distribution of carbon
- Microstructure without residual stress

generated microstructure
Experimental investigations

**Metallographic analysis**

- Grain size measurement
  - Planimetric method
  - Intercept method

- Determination of the microstructural composition (ferrite : martensite)
  - Counting of phases fractions e.g. using a measuring grid ($X_i$ in %)
  - Analysis of the brightness histogram distribution

Grain size measurement by intercept method for a two-phase microstructure (nodularized grey cast iron) [Markoli, B. et al. 2013]

Determination of the phase volume fractions using a measuring grid [www.metallograph.de, 2013]
Experimental investigations

Metallographic analysis

- Grain size measurement
  - Planimetric method
  - Intercept method

- Determination of the microstructural composition (ferrite : martensite)
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Evaluation of the histogram distribution (etched 42CrMo4) [Nünberger, F. 2010]
Experimental investigations

Metallographic analysis after ICA and quenching

22MnB5 800 °C/25 min + quenching + 170 °C/20min
etchant: 1 % alcoholic HNO₃

LH800® 800 °C/25 min + quenching + 170 °C/20 min
etchant: 1 % alcoholic HNO₃
Experimental investigations

Metallographic analysis after ICA and quenching

22MnB5 800 °C/25 min + quenching + 170 °C/20 min
etchant: Klemm 1

LH800® 800 °C/25 min + quenching + 170 °C/20 min
etchant: Klemm 1
Experimental investigations

Mechanical test

Hardness testing depending on $t, T$

Tension test
- Evaluation of the energy absorption capacity

Hardness in relation to the annealing temperature and time. LH800 and 22MnB5

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature</th>
<th>Hardness in HV5</th>
</tr>
</thead>
<tbody>
<tr>
<td>22MnB5, 850 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22MnB5, 800 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22MnB5, as-received</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LH800, 850 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LH800, 800 °C</td>
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<tr>
<td>LH800, as-received</td>
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</tbody>
</table>

ICA + water bath quenching

Tensile test machine. Model Z250 Zwick/Roell [IW]
Modeling - Modell-relevant processes

**Intercritical annealing**

**Temperature**

**Quenching and Forming**

**Temperature**

**lokaler deformation degree**

**Microstructure**

- microstructural components
- Grain size

**Mechanical properties**

- Yield strength, ultimate tensile strength
- hardness

Planned experimental process (schematic)

1. temperature induced phase transformation
2. transformation heat
3. stress induced transformation
Modelling – numerische Beschreibung

Heating process \[ Ac_1 < T < Ac_3 \]

Modelling the phase transformations during the heating

\[ X_A(t, T) = \frac{\varepsilon_{th} - \alpha_{th,F} \cdot T(t)}{\left(\alpha_{th,A} - \alpha_{th,F}\right) \cdot T(t) + \varepsilon_{trans,F \rightarrow A}} \]

\[ X_A \quad \text{austenite phase fraction} \]
\[ \alpha_{th} \quad \text{thermal expansion coefficients of ferrite and austenite} \]
\[ \varepsilon_{th} \quad \text{transformation strain of the phase transformation } F \rightarrow A \]
\[ T \quad \text{temperature} \]
\[ t \quad \text{time} \]

Avrami-function

- Discretize the time-temperature course in a series of small isothermal steps \( \Delta t \)

\[ X_A(t, T) = 1 - e^{-k(T) \cdot t^n(T)} \]

\( k(T), n \) material parameters

Development of thermal expansion during continuous heating (dilatometer curve)

Schematic development of austenite phase fraction
Quenching

Koistinen-Marburger and Wildau-Hougardy law for diffusionless phase transformation (austenite \( \rightarrow \) martensite)

\[ X_M(T) = 1 - e^{-\alpha(M_S-T)^\kappa} \]

\( X_M \) marteniste volume fraction
\( \alpha, \kappa \) constants related to steel composition
\( M_S \) martensite starting temperature
\( T \) temperature

Determination of \( \alpha, \kappa \) form the martensite phase fraction as a function of temperature \((M_S \geq T \geq M_f)\)

Continuous TTT diagram of 22MnB5 [after Naderi et al. 2008]

Martensite transformation curve for the air-hardening steel LH800®. Austenitizing 950 °C/ 10 min [Schaper, M. et al. 2013]
Quenching

Johnson-Mehl-Avrami law for diffusion phase transformation (austenite $\rightarrow$ ferrite/perlit/bainite)

\[ X_{F,P,B}(t, T) = 1 - e^{-k(T) \cdot t^n(T)} \]

- \( X_{F,P,B}(t, T) \): fraction of ferrite, perlite and bainite after transformation time \( t \)
- \( k(T), n(T) \): material parameters

Calculation of the parameters from the curves of the phase transformations (isothermal ttt) at the beginning of the transformation (1 %) and end of transformation (99 %) [Olle, P. 2010]

\[ 0.01 = 1 - e^{-k(T) \cdot \frac{t_{0.01}(T)}{t_0}}n(T) \]
\[ 0.99 = 1 - e^{-k(T) \cdot \frac{t_{0.99}(T)}{t_0}}n(T) \]

\( t_0 = 1 \, \text{s} \)
Next steps

- Manufacturing test for parts made of dual phase steel
  - Intercritical annealing
  - Using different heat treatments
  - Forming and quenching in a die

- Adjustment of a high energy absorption capability of the mixed microstructure

- Model development which describes the intercritical annealing and hardening processes

- Model implementation in ANSYS™

- Model verification by experiments

Thank you for your attention!
References


www.metallograph.de, 2013


Olle, P. 2010 Olle, P.: Numerische und experimentelle Untersuchungen zum Presshärten. Leibniz Universität Hannover, Institut für Umformtechnik und Umformmaschinen, Fakultät für Maschinenbau, Diss. 2010


