

6th International Conference

**HOT SHEET METAL FORMING
of HIGH-PERFORMANCE STEEL
CHS²**

June 4-7, 2017, Atlanta, Georgia, USA

Proceedings

6th International Conference

**HOT SHEET METAL FORMING
of HIGH-PERFORMANCE STEEL
CHS²**

June 4-7, 2017, Atlanta, Georgia, USA
Proceedings

Edited by
Prof. Mats Oldenburg, Luleå University of Technology, Sweden
Prof. Braham Prakash, Luleå University of Technology, Sweden
Prof. Kurt Steinhoff, University of Kassel, Germany

All rights reserved.
No part of this publication may be reproduced or transmitted
by any means, electronic, mechanical, photocopying or otherwise
without the prior permission of the publisher.

© 2017

ISBN: 978-1-935117-66-7

Editorial

The area of hot sheet metal forming of high-performance steel is under continuous development and has seen rapid growth in recent years. The industrial and research community within this field is now well established all over the world. Since its innovation in Sweden in the 1970s, press hardening has become a global technology. The driving forces for the current fast development, with focus on the automotive sector, are the concern for environment and passenger safety. Press hardening and related thermo-mechanical processes represent technologies with outstanding potential to meet global environmental challenges as well as the safety aspects within the transportation sector. What started as a niche technology has developed into a real mainstream area in light-weight design.

To fully support this potential of the technology, further innovations in press hardening steel (PHS) are essential. Research and Development both in academia as well as in industry are the most important prerequisites for continuing innovation. With the Swedish German Centre of Excellence for Hot Sheet Metal forming of High-Performance Steel -CHS²- the University of Kassel (Germany) and Luleå University of Technology (Sweden) have established a worldwide unique competence network to meet the future challenges of hot sheet metal forming technology. Through cooperation with Association for Iron & Steel Technology (AIST), this community is further strengthened in the North American region.

The biannual CHS² conference series has after 5 very successful conferences since 2008 grown into the leading platform for scientific exchange in PHS and related technologies. The conference has established itself as an important international arena, promoting research, networking and innovation. The CHS² conference undoubtedly constitutes the most important event for the international scientific community in the field.

Continuing with the same enthusiasm, specialists from all over the world will get together during the 6th CHS² 2017 and present their latest findings in this key technological field in order to benefit from each other's experience and expertise. Topics like tailored properties, microstructure, material and product performance, new surface coatings and new steels for press hardening as well as pertinent tribological aspects will be in focus in the same way as thermal processing, monitoring, modeling, simulation and, of course, new PHS part innovations and design principles.

Mats Oldenburg
Braham Prakash
Kurt Steinhoff

Table of Contents

Modelling & Simulation I (A1)

- Fracture Mechanics based Modeling of Failure in Advanced High-Strength Steels15**
P. Jonsén, S. Golling, D. Frómeta, D. Casellas, M. Oldenburg
- An Anisotropic Thermo-Elasto-Viscoplastic Model Fully Coupled
with Isotropic Damage for Hot Sheet Metal Forming25**
K. Zhang, H. Badreddine, K. Saanouni
- A Comparative Study of Different Failure Modeling Strategies
on a Laboratory Scale Test Component37**
S. Golling, R. Östlund, M. Schill, R. Sjöblom, K. Mattiasson, J. Jergeus, M. Oldenburg

Heating Technology I (B1)

- Energy Efficient Heating for Hot Stamping49**
S. R. Mickey, M. G. Schoenfelder, J. G. Wuenning
- Development of an Energy-Efficient Burner for Heat Treatment Furnaces
with a Reducing Gas Atmosphere57**
N. Schmitz, J. Schneider, E. Cresci, C. Schwotzer, J. G. Wünnig, H. Pfeifer
- Investigation on Influence of Resistance Heating on Mechanical Properties
and Surface quality of Hot-Stamped Part of High- Strength Steel65**
Y. Wang, W. Liang, B. Zhu, Y. Zhang

Materials & Metallurgy I (A2)

- Development of Press Hardening Stainless Steels
for Body-in-White Application77**
G. Badinier, J. Moreau, B. Petit, C. Boissy, J. Mithieux, S. Saedlou, J. Paegle
- Warm Tensile Deformation and Stamping of Medium Mn TRIP Steels
Microalloyed with Molybdenum and Niobium.....85**
M. Cai, H. Pan, H. Huang, H. Ding, Y. Zhang, B. Rolfe, P. Hodgson
- Study on Bendability of Hot Press Forming Steel with Nb or Nb/V Added.....93**
L. F. Song, H. Z. Lu, J. Zhou, M. T. Ma

| | |
|--|------------|
| A Fracture Mechanics Approach to Develop High Crash Resistant Microstructures by Press Hardening..... | 101 |
| <i>D. Casellas, D. Frómeta, T. Lara, S. Molas, P. Jonsén, S. Golling, M. Oldenburg</i> | |

Coatings I & Special Processes (B2)

| | |
|--|------------|
| Evolution of Phases and Formation of Oxides on Different Galvanized Hot Formed Steel Grades | 111 |
| <i>E. D. Schachinger, S. Kolnberger, J. Faderl</i> | |

| | |
|---|------------|
| Lamellar Structure Formation of Hot-Stamped Galvannealed Coating During Tempering..... | 121 |
| <i>A. Sengoku, H. Takebayashi, N. Okamoto, H. Inui</i> | |

| | |
|--|------------|
| Development of New Al Coating for Press Hardening | 131 |
| <i>J. Oh, S. Kim, Y. Cho, I. Suh</i> | |

| | |
|--|------------|
| Profile-like Hot-Formed UHSS Components Utilizing FBH-Technology - An Alternative Approach to Conventional Hot Stamping | 139 |
| <i>D. Fuss, W. Schmidt, K. Werner, E. Danger</i> | |

Joining & Welding I (A3)

| | |
|---|------------|
| The Processing of Coated Manganese-Boron Steel: Joining Is the Key!..... | 151 |
| <i>T. Manzenreiter, M. Rosner</i> | |

| | |
|--|------------|
| Crash Performance of Magnetic Pulse-Welded High-Strength Steel-Aluminum Connections | 159 |
| <i>A. Rebensdorf, S. Boehm</i> | |

| | |
|--|------------|
| Monitoring of PHS Joining quality with Non-Destructive Testing (NDT)..... | 169 |
| <i>C. Conrad, B. Strass, B. Wollter</i> | |

| | |
|---|------------|
| Novel Alloys and Processing Methods to Produce Self-Pierce Rivets Capable of Joining 22MnB5 Press-Hardened Steel and AA6111..... | 177 |
| <i>S. Van Hall, K. Findley, A. Freis</i> | |

Failure Mechanism I (B3)

| | |
|---|------------|
| Influence of Nb and Mn Content on Resistance to Delayed Fracture of Ultrahigh Strength Hot Stamped Steel Sheets..... | 187 |
| <i>T. Kishimoto, Y. Takemoto, T. Senuma</i> | |

| | |
|---|------------|
| Identified Influencing Factors to Control to Remove Any Hydrogen-Induced Delayed Fracture Risk on Usibor[®] 1500 Parts..... | 195 |
| <i>C. Georges, T. Sturel, P. Drillet, J. M. Mataigne, D. Cornette</i> | |

| | |
|---|------------|
| Liquid Metal Embrittlement During Hot Press Forming of Coated Press-Hardening Steel..... | 205 |
| <i>B. C. De Cooman, W. Jung, K. R. Jo, S. Kang, L. Cho</i> | |
| Influence of Alloy Modifications and Microstructure on Properties and Crash Performance of Press Hardened Steel Components..... | 213 |
| <i>H. Mohrbacher</i> | |
| High-Temperature Tribology I (A4) | |
| High Temperature Tribological Behavior of Thermal-Spray Coated Tool Steels Sliding Against Al-Si Coated Ultra-High Strength Steel | 223 |
| <i>L. Pelcastre, I. Heikkilä, J. Hardell, B. Prakash</i> | |
| Investigation of Tribological Conditions within Partial Hot Stamping..... | 233 |
| <i>P. Schwingenschlögl, J. Steiner, K. Andreas, M. Merklein</i> | |
| Tools & Dies (B4) | |
| A Novel Tooling Technology for Hot Forming Processes..... | 243 |
| <i>P. Åkerström</i> | |
| Metallurgical Optimization of Tool Steels for Hot-Stamping Press Dies | 251 |
| <i>F. Hippenstiel, H. Mohrbacher</i> | |
| Modelling & Simulation II (A5) | |
| Determination of the Essential Work of Fracture at High Strain Rates | 261 |
| <i>S. Golling, D. Frometa, D. Casellas, J. Granström, P. Jonsén, M. Oldenburg</i> | |
| Parametric FEA-Study on the Impact of Cooling Channel Design on Final Part quality | 271 |
| <i>T. Brenne, M. Stippak, M. Düring</i> | |
| A Comparison between Stepwise Modelling and Inverse Modeling Methods for Characterization of Press Hardened Sheet Metals | 281 |
| <i>S. Marth, H. Hügglad, M. Oldenburg</i> | |
| Advances in the Application of the Boundary Element Method to the Thermal Analysis of Hot Stamping Tools Considering Solid-to-Solid Heat Transfer..... | 289 |
| <i>W. Weiß, B. Suhr, M. Kopenig, J. Graf</i> | |

Materials & Metallurgy II (B5)

**Effect of Cooling Rate Below Martensite Start Temperature
on the Yield Strength of a Hot-Stamped Steel Sheet.....299**

S. Tabata, K. Hikida, K. Kusumi

**A Model for Quenching and Partitioning with Press Hardening
of High Strength Steel.....309**

Z. Liu, B. Zhu, Y. Zhang, H. Ding, M. Cai, Y. Wang, B. Rolfe

**Technological Properties of Conventional
and Optimized Press-Hardening Steels317**

M. Maikranz-Valentin

Coatings II (A6)

New Zn Multi-Step Hot Stamping Innovation at Gestamp.....327

P. Belanger, M. Lopez Lage, L. Romero Ruiz, K. Isaksson

**Hot Forming of Zinc Coated Press Hardening Steel. Characterization
of Forming Behaviour and New Process Routes for Mass Production.....337**

R. Kelsch, A. Sommer, H. Schwinghammer, K. Radlmayr,

T. Kurz, G. Lukeneder, J. Faderl

**The Effect of Hot Press Forming Process Parameters
on Coating Layer Behavior of Al-Si Coated Steel345**

H. Kim, H. Son, J. Choi

**Material Properties of Zinc Coated Press-Hardening Steels
for Use with Pre-Cooling Technology353**

T. Kurz, T. Steck, H. Schwinghammer, P. Larour

Failure Mechanism II (B6)

Hydrogen in Hot Forming Steels - Mechanisms and Coating Design.....365

J. Banik, U. Etzold, N. Rössler, N. Ruthenberg

**Hydrogen Absorption and Desorption Kinetics during Hot Press Forming
of Aluminized and Uncoated Press Hardening Steel375**

K. R. Jo, D. H. Sulistiyo, L. Cho, S. W. Kim, B. C. De Cooman

**Atom Probe Study of Prior Austenite Grain Boundaries
of Zinc-Coated Press Hardened Steel383**

C. Hofer, T. Kurz, H. Clemens, R. Schnitzer

**A Coupled Micromechanical-Phenomenological Approach
to Predict Fracture in a Boron Steel391**

P. Samadian, M. J. Worswick, M. A. Wells

Heat Treatment (A7)

| | |
|---|------------|
| The Effects of the Heating Rate and the Incoming Microstructure on the Phase Transformation Temperatures of 22MnB5 Steel | 403 |
| <i>C. Chiriac, R. Sohmshetty</i> | |
| Effect of Austenitizing Parameters on Double Edge Notch Tensile Properties of Press Hardened Steel | 415 |
| <i>L. L. Golem, K. O. Findley, T. W. Brown, P. J. Belanger, J. G. Speer</i> | |
| Influence of Phase Transformation on 22MnB5 Mechanical Behaviour in Hot Stamping | 423 |
| <i>M. F. Novella, G. Venturato, S. Bruschi, A. Ghiotti</i> | |
| Intercritical Annealing - New Heat Treatment Strategies for Tailoring the Stress-Strain Behavior of 22MnB5 | 433 |
| <i>L. O. Wolf, D. Rodman, F. Nürnberger, J.-P. Cordebois, H. J. Maier</i> | |

High-Temperature Tribology II (B7)

| | |
|--|------------|
| Investigation of the Adhesive Wear behavior of Alloyed and Not Alloyed Hot Stamping Tools in Contact with 22MnB5 | 443 |
| <i>F. Neubauer, J. Steiner, K. Andreas, M. Merklein</i> | |
| A Tribological Test Under Press Hardening Conditions for Galling Research | 453 |
| <i>L. Deng, L. Pelcastre, J. Hardell, B. Prakash, M. Oldenburg</i> | |
| Influence of die Temperature on the Tribological Response During Interaction with Al-Si Coated Ultra-High Strength Steel..... | 461 |
| <i>L. Pelcastre, J. Hardell, B. Prakash</i> | |

Tailored Properties I (A8)

| | |
|--|------------|
| Tailoring by Direct Contact Heating During HFDQ | 473 |
| <i>N. N. Field, M. DiCiano, M. D'Souza, A. Gerlich, K. J. Daun</i> | |
| Hot Formed Tailor Rolled Products, Lightweight Solutions with Tailored Properties for Modern Vehicle Structure..... | 481 |
| <i>B. Göddeke, N. Teipel, J. Brecht</i> | |
| Tool and Process Design for Press Hardened Parts with Small-Sized Tailored Properties | 491 |
| <i>N. Pierschel, D. Landgrebe, K. Silbermann, F. Schieck</i> | |

Process Monitoring (B8)

Integrated Manufacturing Quality Control for Press Hardening Steel503

M. F. Peintinger, C. Wood

**Thermographic Process Monitoring - Influences and Importance
of Different Parameters for Temperature Control in Press Hardening509**

S. Sturm

A Smart Process Control Strategy for Press Hardening Production515

L. Wang, B. Zhu, Y. Zhang, Y. Wang, X. An, Q. Wang

Heating Technology II (A9)

Challenges in Heat Treatment for Press Hardening525

H. Lehmann

**In-Furnace Tailored Hot Stamping with Selective Austenitization
by Radiant Heating Design543**

E. Ota, Y. Yogo

Advanced Design for Continuous Roller Furnace for Hot Forming Line551

B. Dvorak, J. J. Tawk, I. Libdeh, T. Vit

Joining & Welding II & Laser Application (B9)

Investigation of Resistance Spot Weld Fracture in Hot Stamped Steels565

*C. O'Keeffe, C. Butcher, M. Worswick, S. Malcolm, J. Dykeman,
P. Penner, C. Yau, E. Biro, R. Soldaat, W. Bernert*

**The Effect of Welding Spot Arrangement on the Energy Absorption
of Hot-Stamped Patchwork B-Pillar573**

C.-K. Chiu Huang, S.-W. Wang, P.-K. Lee, T.-R. Chen, H.-Y. Liou, P.-K. Cheng, Y. T. Chen

High Flexibility in Partial Laser Softening of Press Hardened Steel581

M. Schaefer, P. Scheible, F. Spitz, T. Harrer

Materials & Metallurgy III (A10)

**Ductibor 1000[®] AISi: A New PHS Development
for a Crash Ductility Optimization591**

S. Sarkar, P. Drillet, M. Beauvais, N. Ramisetti, L. Dormegny

**Metallurgical Solutions to Improve Bending and Crash Performance
of Press Hardening Steels601**

J. Bian, H. Lu, W. Wang, A. Guo

| | |
|---|------------|
| Lightweight Chassis Parts Made of MaX1.2HY Press Hardening Stainless Steel | 611 |
| <i>J.-B. Moreau, G. Badinier, P.-O. Santacreu, B. Petit, J.-D. Mithieux, J. Paegle</i> | |

Parts & Processes (B10)

| | |
|--|------------|
| Innovative Solutions for an Effective Hot Stamping..... | 621 |
| <i>M. M. Gharbi</i> | |

| | |
|--|------------|
| Predictive Approach for Crash Performance of Press Hardened Steels and its Application on New Product Developments..... | 629 |
| <i>P. Dietsch, K. Tihay, S. Cobo, S. Sarkar, D. Hasenpouth, D. Cornette</i> | |

| | |
|--|------------|
| Investigation on the Hot bending of 22MnB5 Tubes..... | 639 |
| <i>E. Simonetto, A. Ghiotti, S. Bruschi</i> | |

| | |
|---|------------|
| Sheet Metal Forming in Progressive Dies Assisted by Rapid Induction Heating: Setting of Springback and Product Properties..... | 649 |
| <i>C. Löbbe, S. Hater, M. Kamaliev, L. Hiegemann, A. E. Tekkaya</i> | |

| | |
|--|------------|
| Comparison of Corrosion Resistance of 1500 MPa Grade Hot-Stamped Cold-Rolled and Hot-Rolled (CSP) Press-Hardening Steels for Automotive Application | 663 |
| <i>H. Peng, X. Mao, X. Huang, J. Song, T. Pang, Y. Ma, H. Wang, K. Hu, S. Wang</i> | |

Hotstamping of Light Metals (A11)

| | |
|---|------------|
| Investigations on Aluminum Hot and Warm Forming with the Help of Virtual Process Modeling..... | 673 |
| <i>M. Vrolijk, C. Koroschetz, M. Holecek, K. E. Snilsberg, L.-O. Jönsson, G. Anyasodor, D. Lorenz</i> | |

| | |
|--|------------|
| An Experimental Investigation of Hot Forming Effects on Mechanical Properties of High-Strength Aluminum Alloys AA6082 and AA7075..... | 683 |
| <i>E. Scharifi, D. Kuhnhenh, A. Ademaj, U. Weidig</i> | |

| | |
|--|------------|
| Forming with Thermomechanical Treatment for Manufacturing a Side Sill Demonstrator of AA6082 Aluminum Sheet Alloy | 691 |
| <i>E. Meza-García, A. Rautenstrauch, A. Leonhardt, V. Kräusel, D. Landgrebe</i> | |

| | |
|---|------------|
| Investigation on Short Time Aging of Al-Mg-Si Alloy Sheet under Hot Stamping Conditions..... | 699 |
| <i>Y. Liu, Z. Zhu, Z. Wang, B. Zhu, Y. Wang, Y. Zhang, H. Ding, M. Cai</i> | |

| | |
|---|------------|
| Optimization of Thermo-Mechanical Forming Analysis for Aluminum-Alloy Sheet..... | 707 |
| <i>B. Ghoo, Y. Umezu</i> | |

Materials & Metallurgy IV (B11)

**Effect of Microstructure on Impact Toughness of Press Hardening Steels
with Tensile Strength above 1.8GPa717**

J. Wang, Y. Liu, Q. Lu, J. Pang, Z. Wang, C. Enloe, J. Singh, C. Horvath

Uncoated Press-Hardened Steel Alloys with Improved Residual Ductility.....729

A. Roubidoux

Impact Toughness of a Medium-Mn Steel after Hot Stamping.....737

Q. Lu, J. Wang, Y. Liu, Z. Wang

Tailored Properties III (A12)

**Numerical Modeling of the Crash Performance
of Tailored Hot Stamped Crush Rails749**

C. Peister, M. Worswick, K. Omer, S. Malcolm, J. Dykeman, C. Yau, R. Soldaat, W. Bernert

Damage Characterization of Tailored Hot Stampings759

A. Bardelcik, C. Vowles

**Analysis of the Forming Behavior of Transition Areas
of Partial Press-Hardened Steel at High Strain-Rates.....767**

N. Weiß-Borkowski, T. Marten, T. Tröster, A.-S. Schulz-Beenzen