

7<sup>th</sup> International Conference

**HOT SHEET METAL FORMING  
of HIGH-PERFORMANCE STEEL  
CHS<sup>2</sup>**

June 2-5, 2019, Luleå, Sweden

**Proceedings**

7<sup>th</sup> International Conference

**HOT SHEET METAL FORMING  
of HIGH-PERFORMANCE STEEL  
CHS<sup>2</sup>**

June 2-5, 2019, Luleå, Sweden

Proceedings

Proceedings Edited by:

Prof. Mats Oldenburg, Luleå University of Technology, Sweden

Associate Prof. Jens Hardell, Luleå University of Technology, Sweden

Prof. Daniel Casellas, Eurecat, Centre Tecnològic de Catalunya, Spain / Luleå University of Technology,  
Sweden

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.

© 2019

[www.verlag-wiss-scripten.de](http://www.verlag-wiss-scripten.de)

ISBN: 978-3-95735-104-3

## Editorial

The important area of hot sheet metal forming of high-performance steel, and high-performance materials in general, is in a phase of accelerated development. The industrial and research community within this field is growing all over the world. Since the innovation in Sweden in the 1970s, press hardening of ultra-high strength steels has become a global technology. The driving forces for this fast development, with focus on the automotive sector, are concern for the 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 challenges within the transportation sector. What did start as a niche technology has developed into a globally dominating automotive light-weight design strategy. However, inspired by the continuing success of the press hardening technology, researchers are looking for the next generation of materials for utilization in light-weight structures. Solutions with new materials for press hardening, new hot forming technologies of light-weight and high-performance materials as well as processes for hybrid materials such as steels and carbon fiber reinforced polymer composites are in the pipeline.

To fully support this potential of hot forming technologies, further innovations are essential. Research and Development both on academic as well as on industrial level is one of the most important prerequisites for continuing innovation.

The arrangement of the CHS<sup>2</sup> conferences series has established a worldwide unique competence network. The conferences have been held in both Europe and North-America with the aim to meet future challenges in materials utilization by the promotion of hot sheet metal forming technologies. The biannual CHS<sup>2</sup> conference series has after six very successful conferences since 2008 grown into the leading platform for scientific exchange in hot forming technologies. The CHS<sup>2</sup> conference undoubtedly constitutes the most important event for the international scientific and industrial community in the field.

Consequently, for the 7th International Conference on Hot Sheet Metal Forming of High-Performance Steel CHS<sup>2</sup> 2019 specialists from all over the world are invited to join this unique opportunity for knowledge exchange and to benefit from each other's experience and expertise. Topics like tailored properties, microstructure, mixed materials, performance of new materials and products, 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 innovations and design principles for high-performance components.

Mats Oldenburg  
Jens Hardell  
Daniel Casellas



## Table of Contents

### Heating Technology I (A1)

<b>The Quenching and Partitioning (Q&amp;P) Treatments for Press Hardening .....</b>	<b>15</b>
<i>Y. Sparrer, A. Rüskamp, A. Tenié, J. Lian, S. Münstermann, W. Bleck</i>	
<b>Rolling Beam Furnace for Press Hardening .....</b>	<b>23</b>
<i>D. Angulo, J. Berasategui, A. Sanz</i>	
<b>Research on Influence of Direct Contact Heating Process on Mechanical Properties of High Strength Aluminum Alloy Sheets .....</b>	<b>29</b>
<i>Y. Wang, H. Geng, S. Li, Y. Zhang, Z. Wang</i>	

### Modelling & Simulation I (B1)

<b>Failure Modelling and Experimental Evaluation of a Press-Hardened Laboratory Scale Component with Multi-Phase Microstructure .....</b>	<b>39</b>
<i>S. Marth, S. Golling, R. Östlund, A. Barrero Pijoan, H.-Å. Häggblad, M. Oldenburg</i>	
<b>Dynamic Axial Crush Response of Ductibor® 1000-AS-Effect of Fold Initiator Pattern on Performance .....</b>	<b>51</b>
<i>S. H. Lee, C. Peister, A. Abedini, J. Imbert, C. Butcher, M. Worswick, R. Soldaat, W. Bernert, E. Famchon, P. Penner, C. Yau, S. Malcolm, J. Dykeman</i>	
<b>Fully Coupled Electro-Thermo-Mechanical-Metallurgical Numerical Simulation of 22MnB5 to Explore the Direct Resistance Heating Method Implications .....</b>	<b>59</b>
<i>F. Okigami, D. Faro, R. Coelho, D. Ximenes, J. E. Carvalho</i>	

### Parts & Process I (A2)

<b>Effective Implementation of Hot Cutting of 22MnB5 During Press Hardening: Tooling Performance and Part Properties .....</b>	<b>69</b>
<i>X. Agirretxe, I. Aseguinolaza, D. Casellas, M. Vilaseca, A. Avalos, S. Parareda, E. García, J. Pujante, M. Martínez, N. Cuadrado, G. Ramírez</i>	
<b>A Press Hardening Process for Multi-Material Components .....</b>	<b>77</b>
<i>L. Wikström, S. Golling</i>	
<b>Adhesive Bonding of Direct Hot Formed Zn-Coated PHS .....</b>	<b>87</b>
<i>M. Rosner, E. Schachinger, T. Manzenreiter</i>	
<b>Enhanced Process Limits in the Granular Media-Based Tube Forming Through Axial Feeding .....</b>	<b>95</b>
<i>E. Hoffmann, M. Kamaliev, C. Löbbe, A. E. Tekkaya</i>	

**Materials & Metallurgy I (B2)****Small-Scale Indentation Plasticity of a High-Bendability Martensitic Steel ..... 105***B.-G. Yoo, G.-H. Yang, H. H. Do, S. Y. Huh, J. Jang, S. J. Kim***Fracture Toughness Evaluation of Thick Press Hardened 22MnB5 Sheets for High Crash Performance Applications in Trucks ..... 113***D. Frómeta, S. Parareda, A. Lara, D. Casellas, J. Pujante, P. Jonsén, S. Golling, H. Sieurin, M. Oldenburg***A New Low Density Press Hardening Steel with Superior Performance ..... 123***J. Pang, Q. Lu, J. Wang, C. Enloe, G. Wang, H. Yi***Method for Material Characterization of Edge-Forming Behaviour at Elevated Temperature ..... 131***C. Sunderkötter, T.-P. Post, A. J. G. Blank, I. Pérez, M. Arribas, I. Aranguren, Á. Mangas, R. Rana, C. Lahaije, D. De Caro***High-Temperature Tribology and Coatings I (A3)****Influence of Surface Roughness of Thermal-Spray Coatings on Friction and Wear in Hot Stamping Applications ..... 141***L. Pelcastre, J. Hardell, I. Heikkila, B. Prakash***Study of Wear in Press Hardening Using a Pilot Facility ..... 151***J. Pujante, E. Garcia-Llamas, D. Casellas***Process Window for Patchwork Blanks Regarding Thickness, Friction and Heat Transfer ..... 159***A. Güner, T. Brenne, D. Ling***High Temperature Lubrication in Hot Sheet Metal Forming of Al-Si Coated Boron Steel ..... 167***J. Hardell, S. Archer, L. Pelcastre***Failure Mechanisms (B3)****Hydrogen Embrittlement Resistance of Al-Si coated 1.8GPa Press Hardened Steel Solutions for Body in-White (BIW) Applications ..... 179***S. Cobo, T. Sturel, A. Aouafi, C. Allely, D. Cornette***Hydrogen Induced Delayed Fracture in Hot Stamped Al-Si Coated Boron Steels ..... 191***R. Valentini, M. M. Tedesco, L. Bacchi, S. Corsinovi, D. De Caro***Fatigue of Press Hardened Steels: Drawbacks and Challenges to Unlock the Lightweight Potential of Press Hardening Technology for Heavy Duty Vehicles ..... 201***D. Casellas, H. Sieurin, C. Sunderkoetter, S. Parareda, A. Lara*

<b>Understanding and Predicting the Fatigue Resistance of Press Hardened 22MnB5 .....</b>	<b>211</b>
<i>D. Casellas, S. Parareda, D. Frómeta, M. Martínez, A. Lara, J. Pujante</i>	

## Light Metals I (A4)

<b>Hot Forming of Aluminum AA6016, Simulation Driven Product Development on the Example of an Inner Door Panel .....</b>	<b>221</b>
<i>L. Sandberg, G. Bergman, S. Golling, D. Palo</i>	
<b>Research on Thermal Ductile Fracture Criterion of 7075 Aluminum Alloy .....</b>	<b>229</b>
<i>Z. Wang, W. Huang, B. Zhu, S. Li, Y. Zhang</i>	
<b>Potentialities of Process Cycle Time Reductions at Hot Stamping of Aluminum Alloys .....</b>	<b>237</b>
<i>E. Scharifi, F. Erbskorn, A. Ademaj, Z. B. Kavaklioglu, U. Weidig, K. Steinhoff</i>	

## Process Monitoring I (B4)

<b>Process Monitoring of a Tailored Welded B-Pillar at Renault and Correlation between Forming Analysis and Simulation Results for Different Process Parameters .....</b>	<b>249</b>
<i>S. Graff, C. Pan, J. Lacues, F. Botz</i>	
<b>Process Monitoring and Smart Data Analytics for Hot Stamping Lines .....</b>	<b>257</b>
<i>R. Vollmer, C. Palm, J. Aspacher</i>	
<b>Newest Developments in Thermographic Process Monitoring in Accordance with CQI-9 Norm in Press Hardening .....</b>	<b>265</b>
<i>S. Sturm</i>	

## Materials & Metallurgy II (A5)

<b>Investigation of the Quenching Behavior of Carburized Sheet Metal in Hot Stamping .....</b>	<b>275</b>
<i>A. Horn, M. Merklein</i>	
<b>Microstructural Mechanisms Affecting Fracture Resistance of Martensitic Press Hardened Steel Alloys .....</b>	<b>283</b>
<i>K. O. Findley, S. C. Kennett, L. Cho, L. Golem, J. G. Speer</i>	
<b>Design and Potential Analysis of a New Ultra High Strength Steel (1900 MPa) with Q&amp;P Processes for Car Body Applications .....</b>	<b>293</b>
<i>A. Hatscher</i>	
<b>Material Development and Qualification of Manufacturing Technology for Hot Stamping of Heavy Gage Components .....</b>	<b>301</b>
<i>H. Mohrbacher, D. Tolotti de Almeida, J. H. Corrêa de Souza</i>	

**Modelling & Simulation II (B5)**

<b>Modeling of Ultra High Strength Steel Sandwiches with Lightweight Cores .....</b>	<b>313</b>
<i>S. Hammarberg, J. Kajberg, P. Jonsén</i>	
<b>Study on the Delayed Fracture by Using the Finite Element Analysis based on the Hydrogen Uptake Model .....</b>	<b>321</b>
<i>J. Y. Kong, S. C. Yoon, G. H. Yim, H. J. Kim, B. Y. Min, Y. D. Jung</i>	
<b>Development of Models for Resistance Spot Weld Failure Simulation on Advanced High Strength Steel Sheets Based on an Energetic Fracture Criterion.....</b>	<b>329</b>
<i>D. Dorribo, X. Larráyo, L. Greve, I. Arias</i>	
<b>Simulation and Experimental Research of Hot Stamping and Q&amp;P Heat Treatment Combined Process .....</b>	<b>339</b>
<i>B. Zhu, Z. Wang, K. Wang, Y. Liu, Y. Zhang</i>	

**High-Temperature Tribology and Coatings II (A6)**

<b>Small Change, Substantial Effect - A New Aluminum-Silicon Coating for a Reliable Hot Forming Process .....</b>	<b>349</b>
<i>M. Ruthenberg, J. Banik, M. Köyer, S. Stille</i>	
<b>Tribological Performance of Localized Dispersed X38CrMoV5-3 Surfaces for Hot Stamping of AL-Si Coated 22MnB5 Sheets .....</b>	<b>357</b>
<i>S. Schirdewahn, F. Spranger, K. Hilgenberg, M. Merklein</i>	
<b>Tribological Behaviour of PVD Coated Tool Steel in Hot Forming of Aluminium Alloys .....</b>	<b>365</b>
<i>J. Decrozant-Triquenaux, L. Pelcastre, C. Courbon, B. Prakash, J. Hardell</i>	
<b>Tribological Aspects in Hot Stamping of Ultra-High Strength Steels .....</b>	<b>373</b>
<i>L. Pelcastre, J. Hardell, B. Prakash</i>	

**Joining & Welding (B6)**

<b>Spot Weld Strength Improvement by Optimization of the Welding Parameters on 1.8GPa Press Hardened Steels .....</b>	<b>385</b>
<i>L. Cretteur, Y. Merdji, C. Kaczynski</i>	
<b>Influence of Press-Hardening Process on Resistance Spot Weldability of 22MnB5 with Aluminum-Silicon Coating in a Three-Sheet Stack-Up for Automotive Applications .....</b>	<b>395</b>
<i>O. Sherepenko, Y. Luo, V. Schreiber, M. Wohner, N. Mitzschke, M. Kuhlmann, S. Jüttner</i>	
<b>Improvements in Laser Processing of Door Rings with Laser Machines .....</b>	<b>403</b>
<i>A. Frey, R. Kohllöffel, D. M. Maier, M. Fritz</i>	



<b>Investigation of Resistance Spot Weld Failure under Shear Loading in Die Quenched UHSS Assemblies .....</b>	<b>411</b>
<i>C. Tolton, C. O’Keeffe, M. J. Worswick, P. Penner, C. Yau, S. Malcolm, J. Dykeman, R. Soldaat, W. Bernert</i>	

## Parts & Process II (A7)

<b>Press Hardening Integrated Structuring for Hybrid Components .....</b>	<b>421</b>
<i>M. Triebus, S. Bienia, T. Marten, T. Tröster, K. Dröder</i>	
<b>Development of STAF (Steel Tube Air Forming) Process .....</b>	<b>431</b>
<i>M. Ishizuka, K. Nogiwa, A. Ide, H. Kann, N. Ueno</i>	
<b>A Novel Apparatus for 22MnB5 Hot Tube Bending .....</b>	<b>439</b>
<i>E. Simonetto, A. Ghiotti, S. Bruschi</i>	
<b>Hot Stamping of 1800-2000 MPa Steels .....</b>	<b>447</b>
<i>K. Eriksson, S. Lindgren, P. Muskos</i>	

## Materials & Metallurgy III (B7)

<b>New Stainless Steels for Press Hardening with Improved Fatigue Behavior .....</b>	<b>457</b>
<i>D. Casellas, S. Parareda, A. Lara, M. Abecassis, J. Paegle, P.-O. Santacreu</i>	
<b>The Use of Press-Hardening Technology on Advanced High-Strength Steels .....</b>	<b>465</b>
<i>H. Jirková, K. Opatová, Š. Jeníček, L. Kucerová, E. Meza-García</i>	
<b>Effect of the Deformation Temperature in the Bainitic Transformation During Ausforming Treatments .....</b>	<b>475</b>
<i>A. Eres-Castellanos, F. G. Caballero, C. Garcia-Mateo</i>	
<b>Corrosion Characteristics of Zinc Coated Steel for the Press Hardening Process .....</b>	<b>483</b>
<i>J.-H. Rhee, S.-A. Park, H.-Y. Jung, J.-Y. Kong, T.-W. Kwon</i>	

## Materials & Metallurgy IV (A8)

<b>Effect of Corrosion Products of Aluminized Steel for Hot Stamping on Corrosion Protection .....</b>	<b>493</b>
<i>Y. Suzuki, S. Fujita, M. Fuda</i>	
<b>Technological and Thermomechanical Characterization of Newly Developed 1800 PHS and 2000 PHS Press Hardening Steels .....</b>	<b>501</b>
<i>E. Meza-García, J. Calvo, K. Opatova, H. Jirkova, V. Kräusel, D. Casellas</i>	
<b>Effect of Experimental Setup and Microstructure Features on Bending Performance of Press Hardening Steels .....</b>	<b>509</b>
<i>C. Liu, J. Pang, W. Xu, H. Yi, Q. Lu, J. Wang</i>	

<b>The Determination of the Fracture Behavior of the Different Microstructures of Ductibor® 500-AS Steel .....</b>	<b>519</b>
<i>P. Samadian, C. Butcher, M. J. Worswick</i>	

### High-Temperature Tribology and Coatings III (B8)

<b>Interest of AlSiZnMg Hot Dip Coatings for Press Hardened Steels .....</b>	<b>529</b>
<i>T. M. Amorim, P. Feltn, C. Allély, L. Dosdat, R. Grigorieva, G. Leuillier</i>	

<b>The Study on the Corrosion of 22MnB5 Hot-Forming Parts .....</b>	<b>537</b>
<i>J. An, H. Chen, D. Li</i>	

<b>Extended Aluminium-Silicon Coating Concept with Improved Properties for Existing Hot Forming Applications .....</b>	<b>547</b>
<i>F. Luther, H. Hartmann, M. Debeaux, C. Fritzsche, O. Strauß, M. Graul, K. Krüger, J. Laß, S. Mütze, T. Koll</i>	

<b>Influence of Heating Time on Oxidation Morphology and Cracking Characteristics of Galvannealed Coating in Hot Stamping .....</b>	<b>555</b>
<i>K. Wang, S. Li, L. Wang, Y. Zhang, B. Zhu</i>	

### Heating Technology II (A9)

<b>Heat Treatment System for Thermal Printing Provides Partial Quenching and Tempering in the Press Hardening Process .....</b>	<b>567</b>
<i>H. Lehmann, U. Etzold</i>	

<b>Furnace Design Preventing Hydrogen-Induced Cracking .....</b>	<b>577</b>
<i>T. Chen, R. Chai</i>	

<b>Investigation on Inductive Heating of Sheet Metal for an Industrial Hot Stamping Process .....</b>	<b>585</b>
<i>F. Pfeifer, A. Dietrich, T. Marten, T. Tröster, B. Nacke</i>	

### Materials & Metallurgy V (B9)

<b>The Effects of Non-Isothermal Plastic Deformation on the Martensitic Transformation of 1.8 GPa Press Hardening Steel and the Implications toward Production Paths .....</b>	<b>597</b>
<i>C. Chiriac, G. Luckey, M. Broda</i>	

<b>Improvement of Hydrogen Embrittlement Resistance of Press-Hardening Steels .....</b>	<b>611</b>
<i>M. Maikranz-Valentin, G. Genchev, D. Mirkovic</i>	

<b>Hot-Formability and Mechanical Behaviour of a Tungsten-Containing Low-Carbon Complex-Phase Steel .....</b>	<b>619</b>
<i>R. Rana, T. Kop</i>	

**Modelling & Simulation III (A10)**

<b>A Multi-Scale Friction Model for Hot Stamping .....</b>	<b>629</b>
--	------------

*J. Venema, J. Hazrati, D. Matthews, E. Atzema, T. van den Boogaard*

<b>Sub-Critical Quenching of an 1800 MPa Grade of Press Hardening Steel: Experiments and Model Validation .....</b>	<b>637</b>
---	------------

*C. Bourque, A. Bardelcik, M. Wells*

<b>A Novel Method for Modelling of Cold Cutting of Microstructurally Tailored Hot Formed Components .....</b>	<b>645</b>
---	------------

*P. Jonsén, A. Svanberg, G. Ramirez, D. Casellas, R. Hernández, S. Marth, H.-Å. Häggblad, M. Oldenburg*

**Parts & Process II (B10)**

<b>On Tailored-Properties Parts with Quenched and Tempered Roll Formed Automotive Components .....</b>	<b>655</b>
--	------------

*C. Rouet, R. Dallinger, C. Wagner, T. Kurz*

<b>Development of a Tailor-Welded Hot Stamped Side Frame Member .....</b>	<b>665</b>
---	------------

*M. Tummers, C. Peister, J. Imbert, M. J. Worswick, S. Malcolm, J. Dykeman, C. Yau, R. Soldaat, W. Bernert*

<b>Development of Selective Cooling Approach to Generate Easy-to-cut-zones for Hot Formed Lightweight Automotive Components .....</b>	<b>673</b>
---	------------

*I. O. Yilmaz, O. Saray*

**Parts & Process III (A11)**

<b>Method for Characterizing Functional Graded Properties of 22MnB5 .....</b>	<b>683</b>
---	------------

*E. Scharifi, T. Schade, A. Ademaj, U. Weidig, K. Steinhoff*

<b>Press Hardened B-pillar with CFRP Patch, Simulation &amp; Crash Test .....</b>	<b>693</b>
---	------------

*R. Östlund, K. Hedström*

<b>Developments for a Reduced Total Cost of Ownership .....</b>	<b>701</b>
---	------------

*W. Tuschek, H.-U. Dorst, J.-P. Schmiing*

<b>Effect of Contact Pressure in die Quenching on Strength of Hot-Stamped Parts .....</b>	<b>709</b>
---	------------

*N. Nakamura, K.-I. Mori, Y. Nakagawa, T. Miyachi*

**Materials & Metallurgy VI (B11)**

<b>Mechanical Behavior of New Press Hardening Steels at Elevated Temperatures and Technological Modeling of their Processing .....</b>	<b>719</b>
--	------------

*K. Opatová, H. Jirková, E. Meza-García, Š. Jeníček, J. Vrtáček*

**Application of Quenching and Partitioning Processes  
to Welding and Press Hardening** ..... 727  
*F. Forouzan, E. Vuorinen, M. Oldenburg, H.-Å. Häggblad*

**Loading Rate Effects on Apparent Bendability of 1.8 GPa PHS** ..... 737  
*N. Ramiseti, J. Wang, C. M. Enloe, Q. Lu, L. Reini*

**BTR2000 - A New Uncoated Ultra-High Strength Hot Forming Steel** ..... 749  
*M. J. Holzweissig, G. Frost, K. Bake, A. Frehn*

## Process Monitoring II (A12)

**Intelligent Process Optimization for Highly Efficient Productions** ..... 759  
*F. Ebner*

**Long-Period Intelligent Control in Hot Stamping Production** ..... 767  
*L. Wang, K. Wang, S. Li, X. An, Y. Zhang, B. Zhu*

**Industry 4.0 Implementation in Gestamp Press Hardening Technology -  
Process Control and Performance Improvement** ..... 775  
*B. González, D. Vidal*

## Light Metals II (B12)

**A Feasibility Study on High Efficiency Hot Stamping  
of 7075 Aluminum Alloy Sheet** ..... 785  
*Y. Liu, L. Wang, S. Li, Y. Zhang, Y. Wang*

**Application of HFQ® Technology to Form B-Pillar Panel  
from High Strength AA7075 Aluminum Sheet** ..... 793  
*M. Mohamed, D. Szegda, F. Melotti, P. Sailard, F. Adzima, M. Ziane*