FROM DESIGN / CONCEPT TO VIRTUAL REALITY – VIRTUAL HOT FORMING ENGINEERING ILLUSTRATED

get it right®

TECHNICAL PAPER

David Lorenz, Martin Holecek, Mark Vrolijk, Matthias Hoss, Bahia Dahmena, Mark Doroudian, Harald Porzner, ESI GROUP

.Johan Friberg, Christian Koroschetz, Martin Skrikerud, AP&T

SUMMARY

Regulations in safety and fuel efficiency are putting more and more pressure on the Automotive Industry to move towards lightweight solutions. Consequently, innovative research and a 3G engineering approach (gage, grade and geometry) has led to a number of alternatives for commonly used steels and designs. Aluminum alloys, press hardened steels, advanced and ultra-high strength steels (AHSS and UHSS) and carbon fiber reinforced plastics (CFRP) have displaced commonly used materials and require new designs with different grades and manufacturing methods. Unfortunately, this causes many new challenges with respect to design, manufacturing process, and production cost or production cycle. In contrast, the development time of car platforms has shortened dramatically, meaning that reducing the number of real prototypes is essential to ensure goals are still reached on time. In order to be able to replace real prototypes, virtual prototypes must obviously be as precise as the real ones.

To answer this challenge, sheet metal forming has moved on to die face design based on B-spline geometry in order to save time in the interaction with CAD, in the iterative process of part development and tooling. Any possible hold due to required changes in geometry must be removed. Tool surfaces, and tool and blank meshes must be precise to guarantee an accurate description of contact surfaces and accurate simulation results – and this as early as possible in the process. There must be no trade-offs with the time needed to set up a simulation model nor simulation time. All physical effects of the process must be captured accurately.

Hot forming is a process that involves additional engineering challenges next to traditional tasks known from cold forming. Hot forming die face and die process engineering will be illustrated with a realistic dash panel example – from customer request to virtual reality, including the following virtual engineering steps:

- Quoting: Blank unfolding/flattening, nesting, material usage and price for the part, thinning/strains/FLD estimation based on one step simulation
- Die face design: Tipping with automatic minimization of draw depth and undercut, part preparation like closing holes, smoothing of the part outline and a powerful part surface extension functionality, binder surface creation through dedicated parametric 2D profiles and a powerful export functionality that allows forwarding most of the required process information to PAM-STAMP, making it possible to start a standard drawing simulation with only a few clicks
- Feasibility and validation of forming: Transport, gravity, stamping, reliability of hardening, die spotting, unloading, cooling on air, distortion
- Validation of the cooling channel design: Via heat transfer and link with forming or via computational fluid dynamics and conjugate heat transfer
- Virtual inspection of a complete hot forming line including simulation results in a virtual reality system

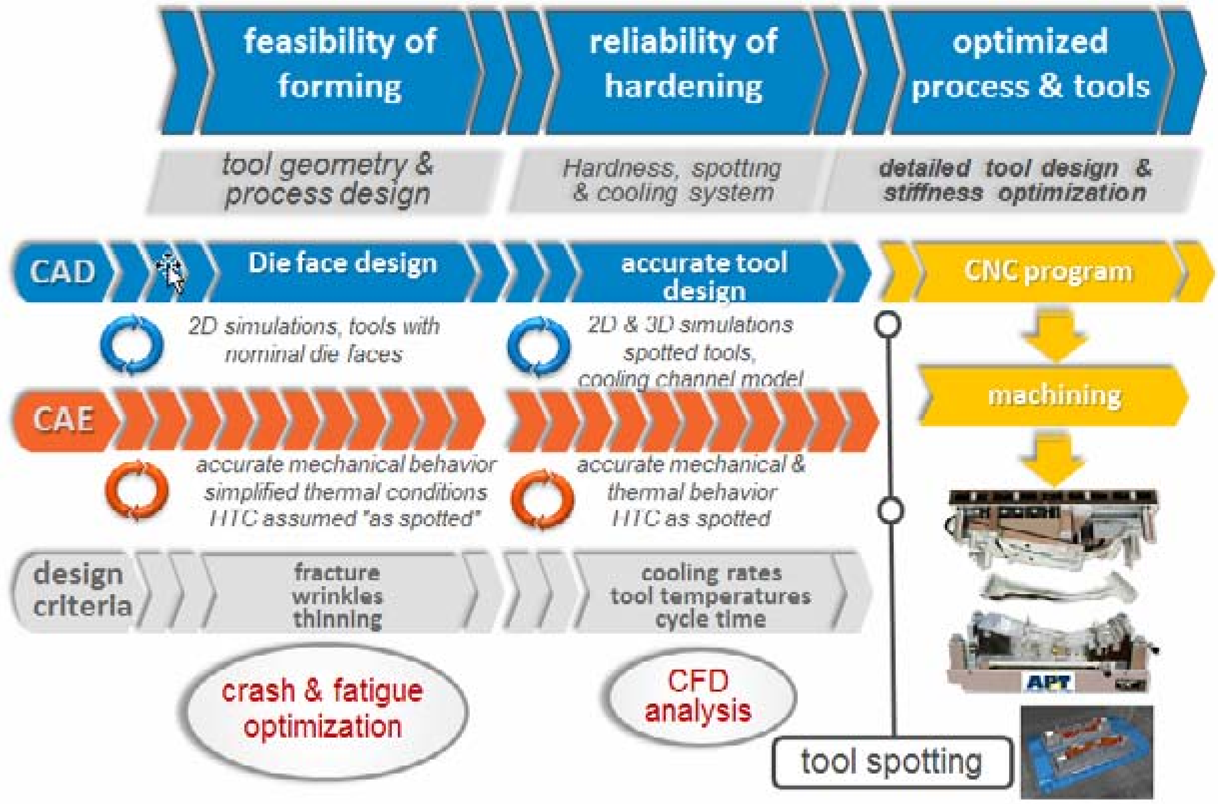

Fig. 1: The complete process illustrated

MATERIAL COST ESTIMATION

Car bodies are made from a few hundreds metal parts. In the production process, these three-dimensional parts are cut from two-dimensional sheet metal before they are press-formed and (spot- or laser) welded together by robots. The two-dimensional sheet metal is available as long rolls, better known as 'coils', which can have different widths, numerous material properties and variable prices and nowadays can even have different thickness along the roll. Taking the final part geometry as a starting point, the application can quickly develop the minimum flattened blank outline and determine the optimal nesting layout in the coil corresponding to the lowest material cost. The following describes in few sentences the general workflow and available functionalities to effectively perform the job-to-be-done.

PART GEOMETRY DEFINITION

The part can be imported as a surface or solid model. Dedicated functionality for extracting the top and bottom surface of the solid model, as well as generation of the mid-surface are available in order to calculate correctly the flattening of the part geometry at the neutral fiber. The selected part can be assigned with required material and thickness information.

BLANK OUTLINE DEFINITION

The bidding solution is based on a one-step solver. In no time it determines accurately the flattened blank outline (even if undercut areas exist), based on the full 3-D part model and few process parameters like restraining force, material definition and thickness. In addition to the developed blank outline, part feasibility can also be directly and thoroughly analyzed through various contours like thinning, thickness and forming limit diagram (FLD). Direct import of a blank outline is supported as well. It is also possible to import one or more optimized blank outlines generated with e.g. an incremental simulation.

TECHNICAL PAPER

NESTING

The developed blank outline can be used in the nesting process. The outline can be smoothened and can be applied with or without addendum region generation through constant offset of the outline. Multiple nesting layouts are supported like “One up”, “Two up”, “Mirror” and “Transfer Die” for optimal material utilization calculation.

AUTOMATIC REPORTING

The solution includes a fast and automated report generator for quotation of the part material. This functionality includes export of material utilization, fall off, pitch, coil width, blank area and pictures of the nesting sequence and developed blank outline.

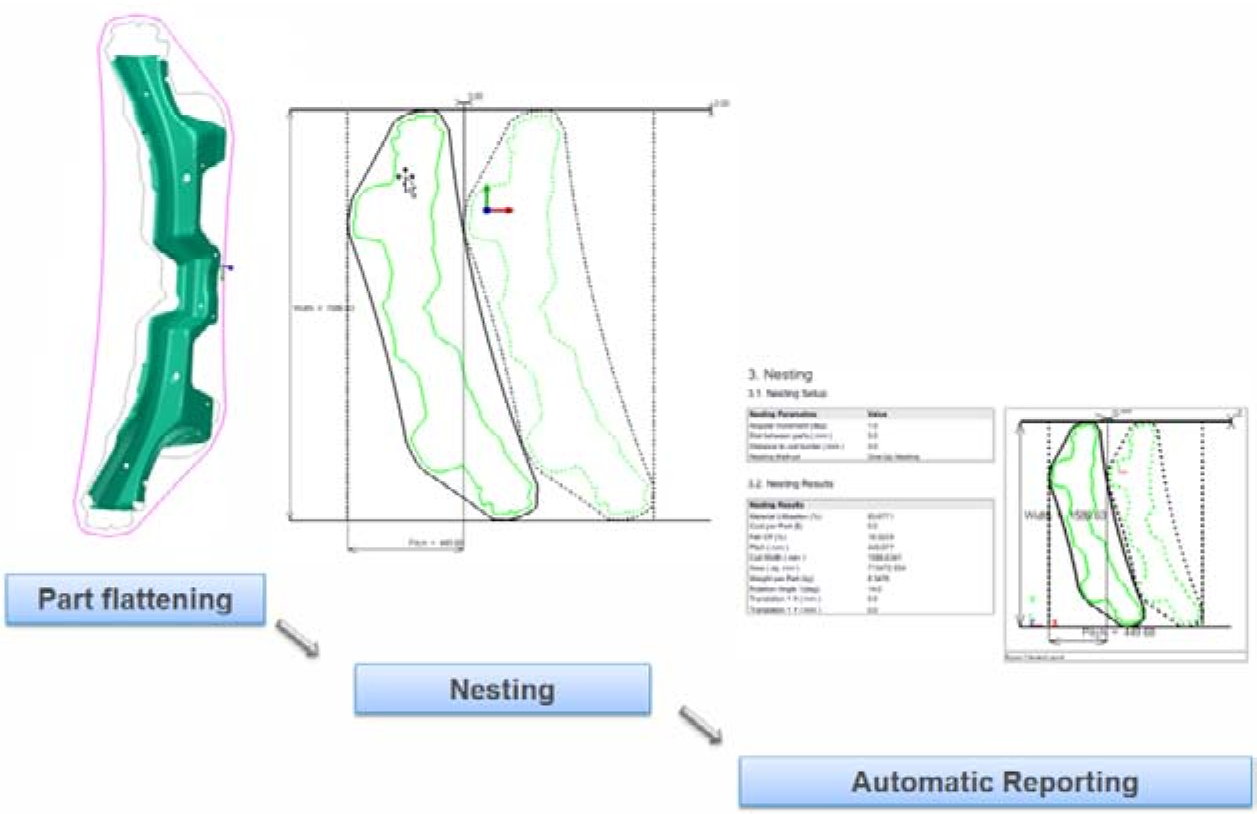

Fig. 2: Material cost estimation - Blank outline and nesting

DIE FACE DESIGN NEXT GENERATION

Nowadays die face design is moving towards CAD environment. Iterations are done directly inside CAD and on native CAD data. The tool used for die face design must support the user in all phases of the process design cycle: from the very early conception phase, through feasibility studies until the final validation. An optimum with respect to performance and accuracy needs to be established for each of these separate steps. Die face design should be based on B-Spline geometry in order to keep the solution fast, powerful, flexible and compliant to the automotive industry standards. Any possible hold due to required changes in geometry must be removed. Surfaces must be accurate to guarantee an accurate description of contact surfaces and accurate simulation results – as early as possible

CUSTOMER CHALLENGE

Automotive sheet metal forming parts come from the design department and often consider only aesthetics (outer panels) or functionality (reinforcements, beams etc.). Normally no, or very little, consideration is given to manufacturability. This is the job of the process design department or toolmaker: find ways to create the part in a robust and cost-optimized way. In most cases the time-pressure is huge (and ever increasing), but still many variants of the die face design and process need to be considered before an optimum (manufacturability and cost!) is found.

Typical Workflow

Starting from the part geometry, a first die face design for the first draw die is quickly drafted and evaluated for general feasibility like occurrences of cracks and wrinkles. As the first design will not normally fulfil all criteria, iteration loops are run to optimize the die face design and stamping process parameters. These iterations normally consist out of the following: Complete or partial part modifications coming from the design department, geometrical addendum modifications to eliminate wrinkles, cracks or to optimize the trimming conditions, process modifications to overcome cracks and wrinkles and improve the general robustness of the process, reduction of blank size for material cost optimization, propose part modifications in case a feasible or robust process cannot be guaranteed.

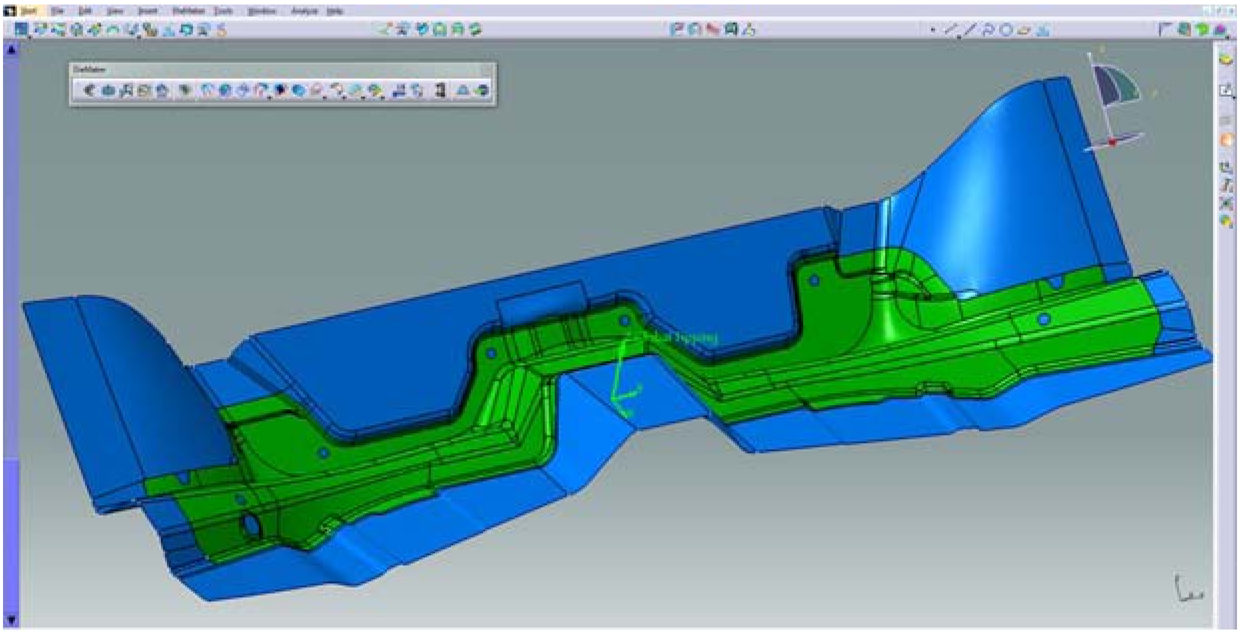

Fig. 2 – Die Face Design based on CATIA DIEMAKER

FAST LINK WITH SIMULATION TO MINIMIZE THE TIME TO SET UP A SIMULATION AND SPENT FOR ITERATIONS

Support for the many iterations, which is characteristic of the early design phase of a car project, is covered through a dedicated link between both the die face design and the simulation environment. The final goal of virtual prototyping is to get the part out of the press ‘right first time’. However, this requires beforehand a fast number of iterations within the simulation environment to come to a robust and feasible solution for the production of the component. The first simulation will usually be far from the final feasible design. In addition, the part geometry itself will frequently change during this phase: small features can be added or removed, or parts can be completely re-designed. Historically the CAD model of the tool was imported without additional supporting information. A blank outline and drawbeads (if required) had to be defined along with their data and properties, resulting in time-consuming generation of the final tooling. This resulted in cumbersome and time-consuming iteration with a lot of manual work for the engineer, and with a huge risk for project delays and budget overspending. On top of that, also errors appeared between subsequent iterations. All of ESI-Group’s solutions for die face design include a streamlined and efficient transition between die face design and the simulation based analysis tool, by reducing the amount of required user-interaction to an absolute minimum. smoothened and can be applied with or without addendum region generation through constant offset of the outline. Multiple nesting layouts are supported like “One up”, “Two up”, “Mirror” and “Transfer Die” for optimal material utilization calculation.

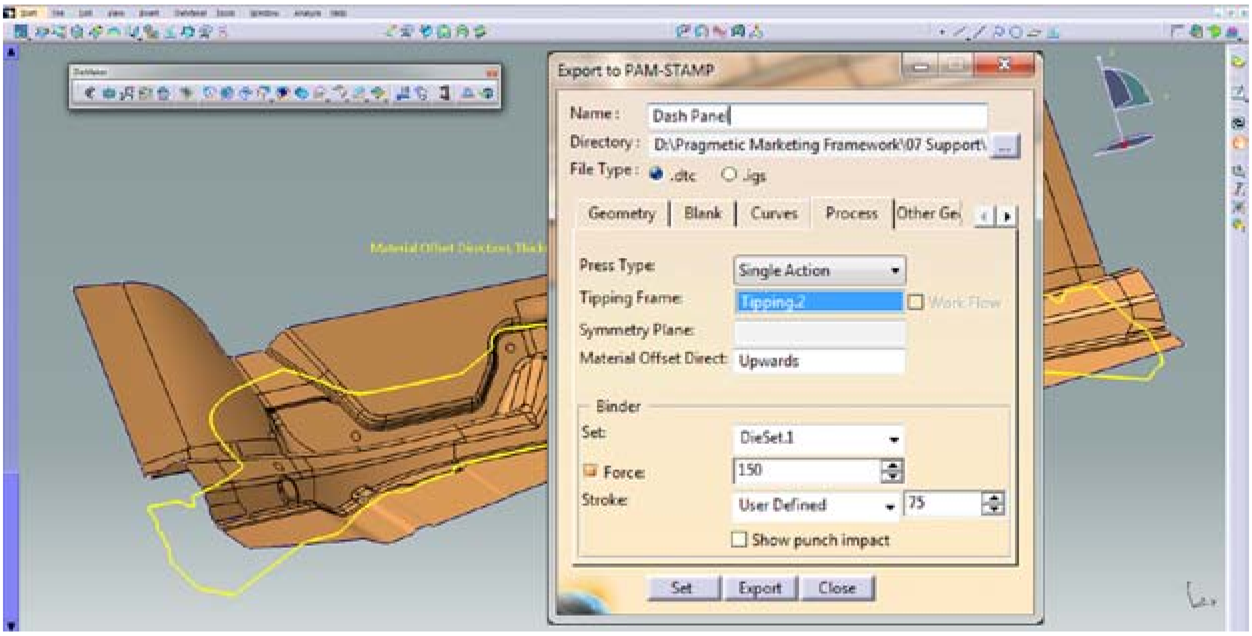

Fig. 3 – Quick link with simulation

The quick link with simulation saves up to 80% of the time needed for setting up a draw die simulation. Not only are geometrical data (like punch and binder geometry) transferred, but also process data like binder forces, binder travel distances, part material definition and thickness and material offset direction and finally car and tipping system of coordinates are kept in order to enable advanced inter-disciplinary engineering.

ACCUATE NUMERICAL METHODS – KEY FOR ACCURATE VIRTUAL PROTOTYPING

Accurate contact permanently prohibits the nodes of the blank sheet from any penetration of the volume of the element of the tool during a calculation. The nodes are kept exactly at the surface of the element owing to the contact forces being precisely calculated.

Today, all explicit simulations in PAM-STAMP are carried out with accurate contact and high quality numerical settings, no matter if in the feasibility or validation stage. Accurate contact is applied to huge simulation models with 10 million or more degrees of freedom. At the same time, the explicit method with many short time steps allows for the precise integration of the material history in the drawing phase. It is not possible to run accurate contact with many short time steps on large models with implicit solutions because it would be too time consuming.

Working with accurate contact, short time steps to integrate the material law accurately and from the beginning accurate numerical settings has several advantages:

- There is no risk of finding - late and thus costly - issues like cracks or wrinkles in the validation phase, just because of different (contact or numerical) settings in the feasibility stage. Accurate contact in all simulation stages and providing an accurate representation of the tool topology and tool mesh from the beginning helps to avoid this problem, which otherwise can take a lot of time to compensate for the encountered issues.

- The accurate computation of plasticity and residual stresses after forming is guaranteed
- The press force is predicted precisely
- Accurate contact and ironing are the basis for accurate die spotting – which can save a lot of time especially in the development of a press hardening die

Accurate contact is relatively computational intensive. However, with the new triple speed mode in PAM-STAMP, simulations with accurate numerical settings are now also possible even in the earliest stage of the project. Consequently, any numerical compromises in the feasibility stage can now be discarded.

TRIPLE SPEED MODE FOR EXPLICIT SIMULATIONS

A new solver option in PAM-STAMP allows analysis speed up in the same manner as conventional numerical tuning, but without a loss in quality. This is shown with a body-side from the Mitsubishi Outlander.

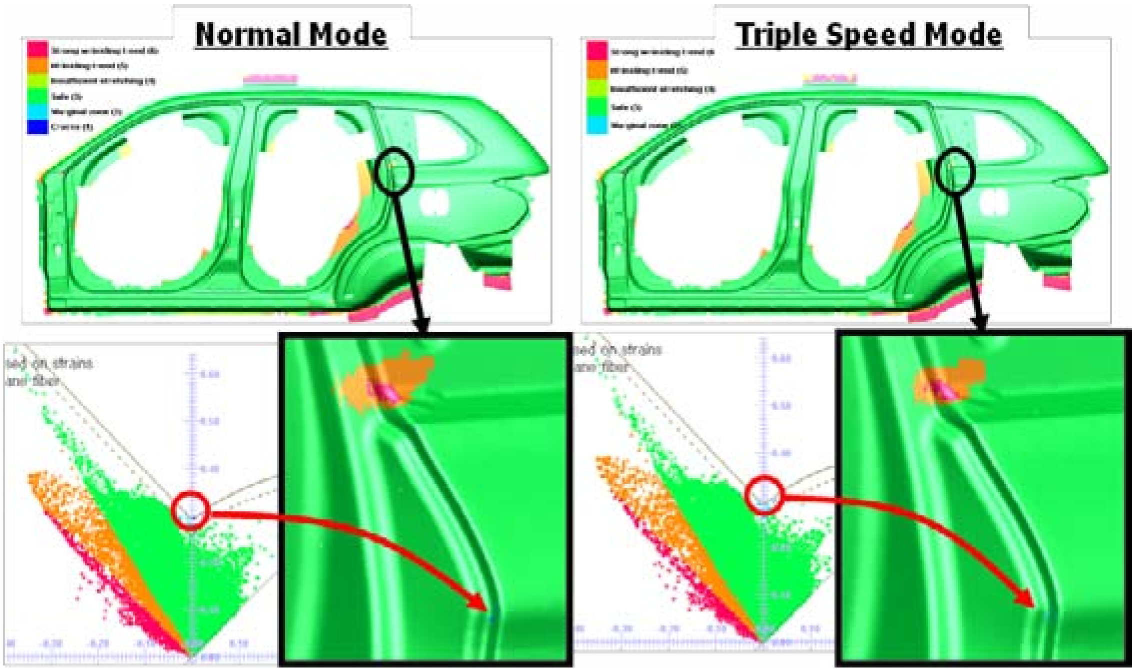

Fig. 4: Comparison of results – with and without triple speed mode

Specifically, a 3-4X analysis speed up in the drawing phase, with no associated loss of quality, allows these high quality feasibility studies to be completed within the same time constraints as conventional feasibility studies. In combination with multi-core processors, very short simulation times can be achieved. With the new solver option and a four core CPU, a total speed up of 12-15 X is possible compared to a one core simulation without the new solver option. Simulation times are now short enough for formability stage precision to be used in the early feasibility phase – all with precision forming quality provided by PAM-STAMP. Consequently, it is no longer necessary to tune explicitly simulations by numerical means i.e. mass scaling, numerical settings, mesh coarsening etc. - to achieve feasibility run time and consequently pay with a loss of quality. Moderate baseline settings can be used in the feasibility stage. Because the new solver development is not at the expense of quality, it is also applicable in the validation / formability phase. Consequently, it is possible to achieve, with standard baseline settings for conservative engineering, the same simulation time as with tuned baseline settings, or even less. With the new solver, it is also no longer necessary to use coarser meshes or any other kind of model simplifications to achieve less simulation time. This allows for high-quality results with a reasonable simulation time at the earliest stage possible. The figure above shows the efficiency of the triple speed mode. The model used for the verification was provided from Mitsubishi Motors. Without loss of quality, calculations with triple speed mode are faster by a factor of 3.7 compared to the normal mode.

HIGH QUALITY RESULTS WITHOUT TRADE-OFF IN COST OR TIME

As a consequence of all the new developments, trade-offs between simulation time and result quality can now be discarded, and realistic virtual prototyping is now possible. The tools for die face design from ESI produce high quality die faces based on B-Spline geometry, which represent an accurate description of the contact surfaces. An automatic transfer of data to PAM-STAMP and set up of the drawing simulation minimizes work time. Iterations on part geometry, die face, binder, draw beads and any other process related parameters are completed in no time. Today, the PAM-STAMP solver always works with accurate contact in the drawing operation, no trade-offs in numerical settings and, if needed, with geometrical draw beads and any advanced material model for the yield surface and hardening. The new triple speed mode in conjunction with four or eight core parallel processing delivers simulation results in a breath-taking short response time, even on low cost computers. Simulation times are amazingly short on computers with eight cores, a solid-state drive, and a more recent processor. The speed up with an eight-core configuration and triple speed mode can be up to 20 against a single core configuration with no triple speed option. This allows constant high quality results from early feasibility to high-end formability, and consequently the minimization of the overall engineering cost.

FORMING PROCESS – FEASIBILITY AND VALIDATION

PROCESS

The forming simulation is for the illustrated example done in six steps: Transport, gravity, stamping, quenching, unloading, and cooling on air.

In the stamping simulation model, the lower die is held with a significant force (during the whole stamping process) in the upper position until the punch is in the closed position. The closed upper and lower die are moved during flanging by the punch until the stop position of the punch is reached. The flanging dies do not move. There is no lower stop for the lower die, and no spacer. In the quenching stage, punch & flanging tools are static; the lower die is kept fixed with a significant force. After unloading, the blank will cool on air.

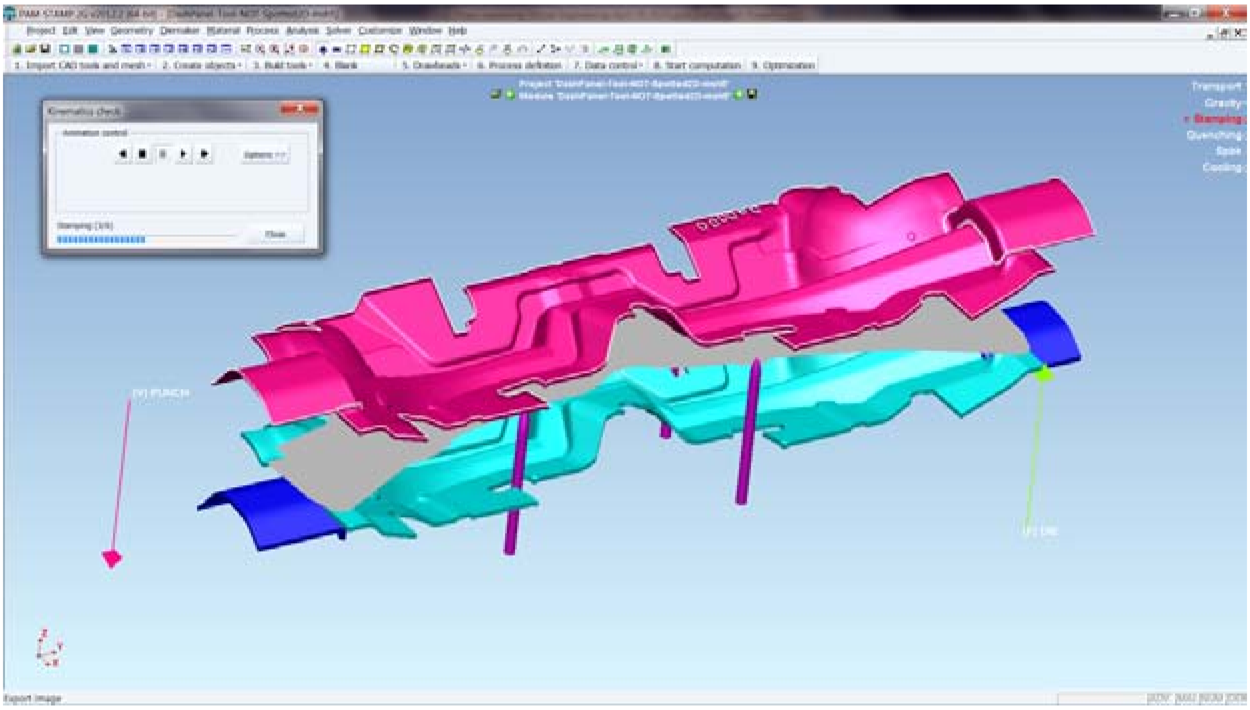

Fig 5: Illustration of the 6 forming steps

IMPORTANT RESULTS

To judge virtually a hot forming process, particular results are of interest.

- *Percentage thinning* – The most important result to make sure that crash performance is still to specifications and no cracks will occur.
- *Wrinkles* – They often come and go in hot forming because they are in most cases not controlled by blankholder forces and drawbeads. It is thus most important to check that wrinkles are flattened out at the end and do not fold.
- *Die spotting* – To guarantee that 90% or more of the die face do exceed a minimum contact pressure that is required to achieve the necessary temperature levels at the end of quenching in the planed cycle time.
- *Temperature, cooling rates and microstructure* – The most important results to make sure that the hardness (also a computed result) of the formed part is to specifications. Hardness is a function of chemistry and cooling rates that are computed based on the temperature history. Temperature and microstructure are a function of chemistry, thermo-physical properties, contact pressure, blank thickness and cooling capability.
- *Distortion* – To make sure parts are within defined tolerances.

PERCENT THINNING

Percent thinning shows positive and negative changes in the nominal blank thickness. Blue wavy sections indicate wrinkles.

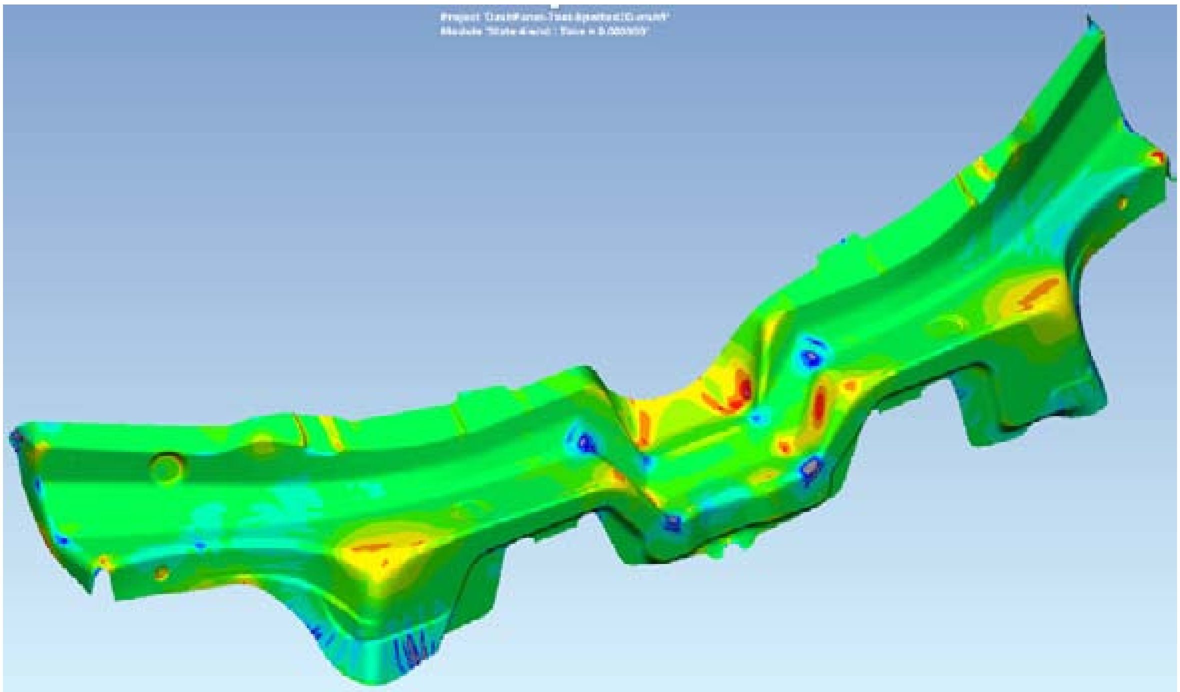

Fig. 6: Percent thinning versus nominal blank thickness

WRINKLES

Especially in a hot forming process, wrinkles can come and go. In case not flattened out at the end they could even destroy a die. PAM-STAMP simulates wrinkles with no compromises – as they would occur in reality, including folding. Only an explicit simulation scheme can do that – thanks to the many small time steps and the ability to manage significant geometrical non-linearity without slowing down or even stopping the simulation.

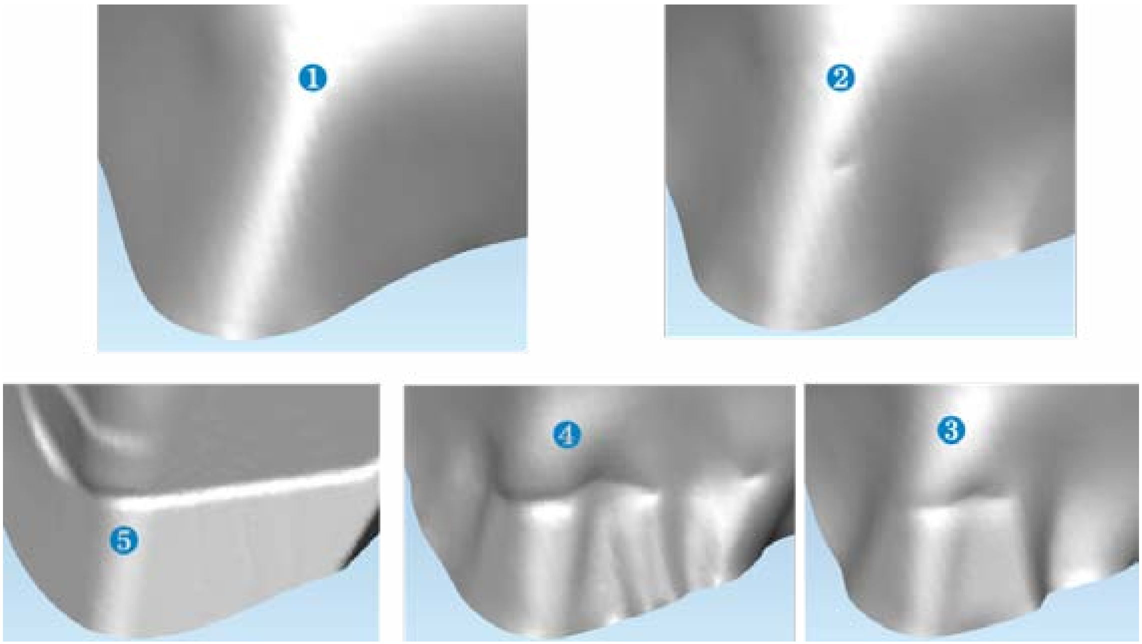

Fig. 7: Evolution of wrinkles during forming

DIE SPOTTING

For the evaluation of temperature, microstructure and distortion there are two options available.

- A first evaluation with the nominal die surface
- A precise evaluation with a spotted die surface as used in production

Only with a spotted die surface it is possible to get realistic results. With PAM-STAMP, it is possible to generate an as spotted die surface and process both types of simulations.

Fig. 8: Spotted (blue) and non-spotted (red) die face

TEMPERATURE, MICROSTRUCTURE AND DISTORTION

Below illustrated are a few typical results. It is clearly visible that the process is OK when using the spotted die face. The results with the spotted die face are always on the right side. The difference in the final distortion is about a factor of 2.

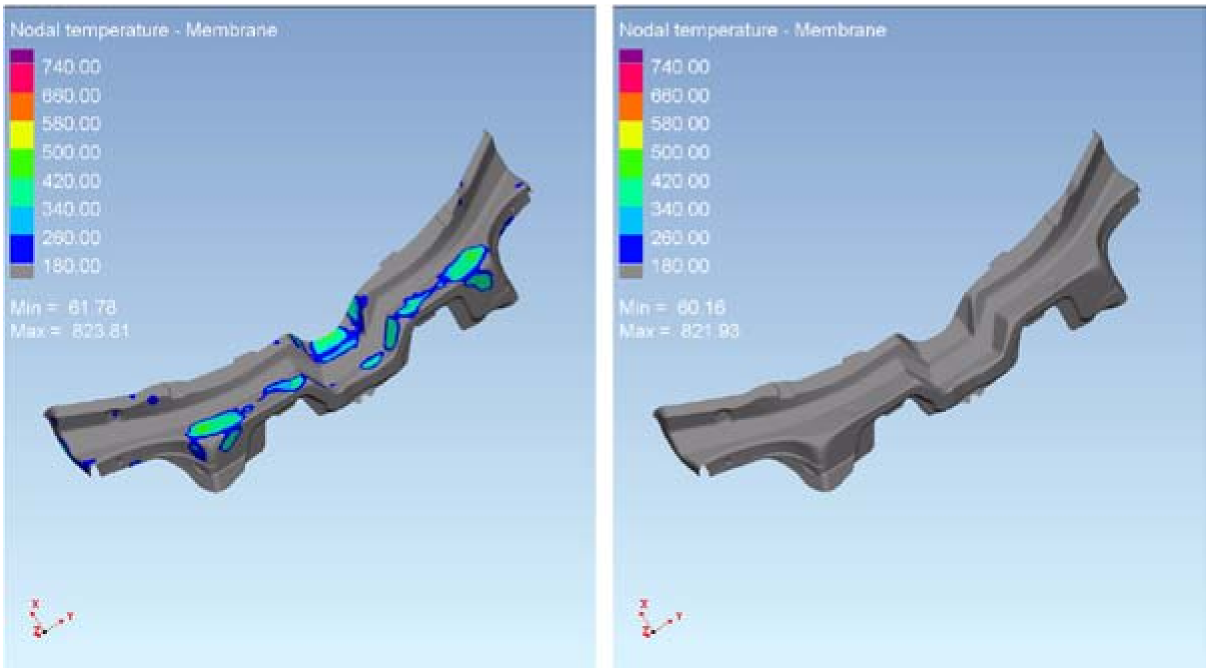

Fig. 9: Temperature at the end of quenching – Spotted (right) and not spotted die face

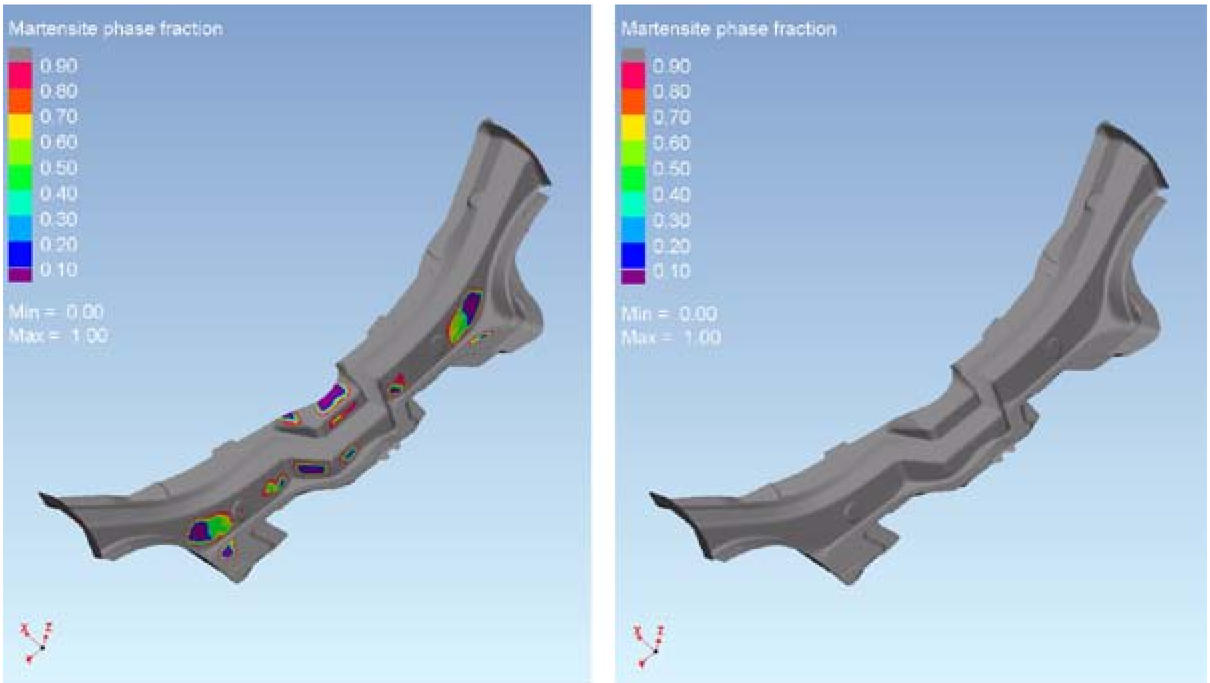

Fig. 10: Martensite formation at the end of quenching – Spotted (right) and not spotted die face

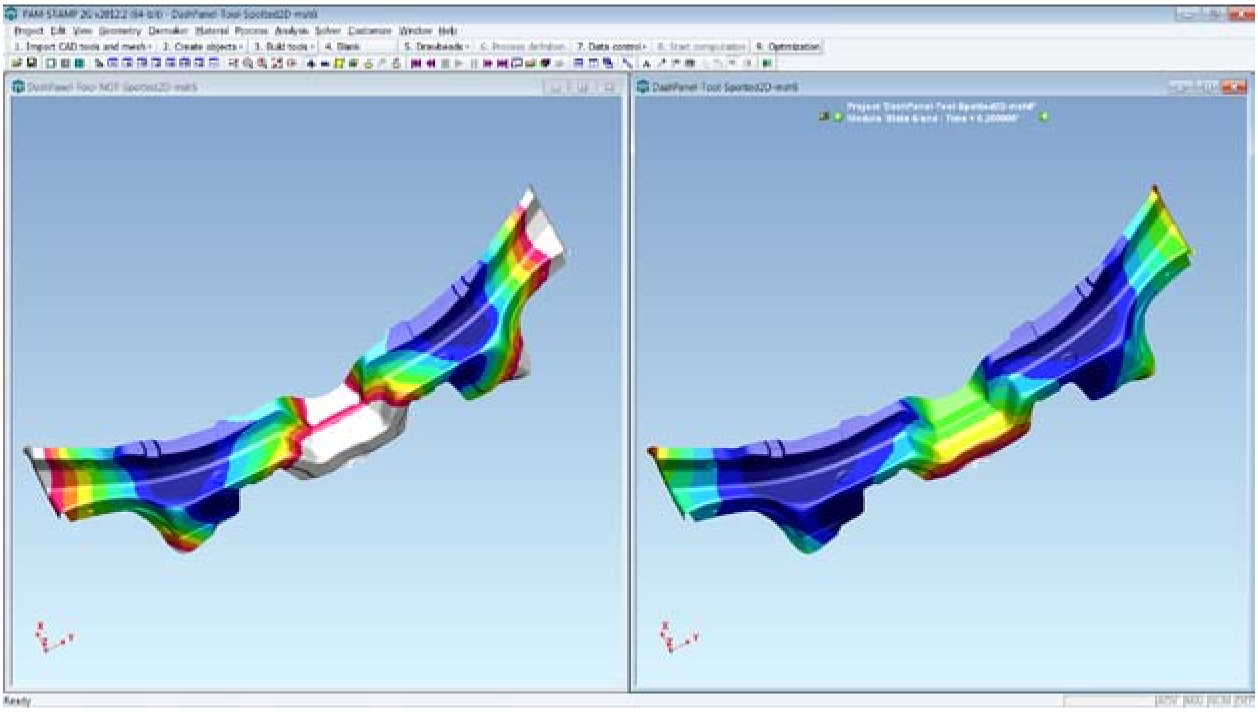

Fig. 11: Distortion after cooling on air – Spotted (right) and not spotted die face

COOLING CHANNEL DESIGN

Cooling channel design at AP&T is being done by the demands of the tool e.g.: part shape (geometry), cycle time, volume, …

5-Axis Milling

Typically, the diameter of the 5-Axis drilled holes is a function of the total volume available at the press. Ideally, the tool should use 100% of the water available to maximize the cooling capabilities of the water supply.

Vertical drilled holes, "Baffles"

Baffles can be used in situations where the form depth or shape exceeds the manufacturing capabilities. Baffles are an effective cooling solution. However they create a significant pressure increase within the cooling system and should only be used when required.

The cooling channel design can be evaluated either with a heat transfer analysis that takes into account the details from the stamping and quenching simulation and cycle times, or with a fully coupled conjugate heat transfer analysis.

These delivers engineering insight into pressure drops, coolant velocity, coolant temperature, heat transfer in the cooling channels and die face temperatures.

The heat transfer analysis below shows temperature peaks between the die blocks of the initial design. The final design does not show those peaks any more.

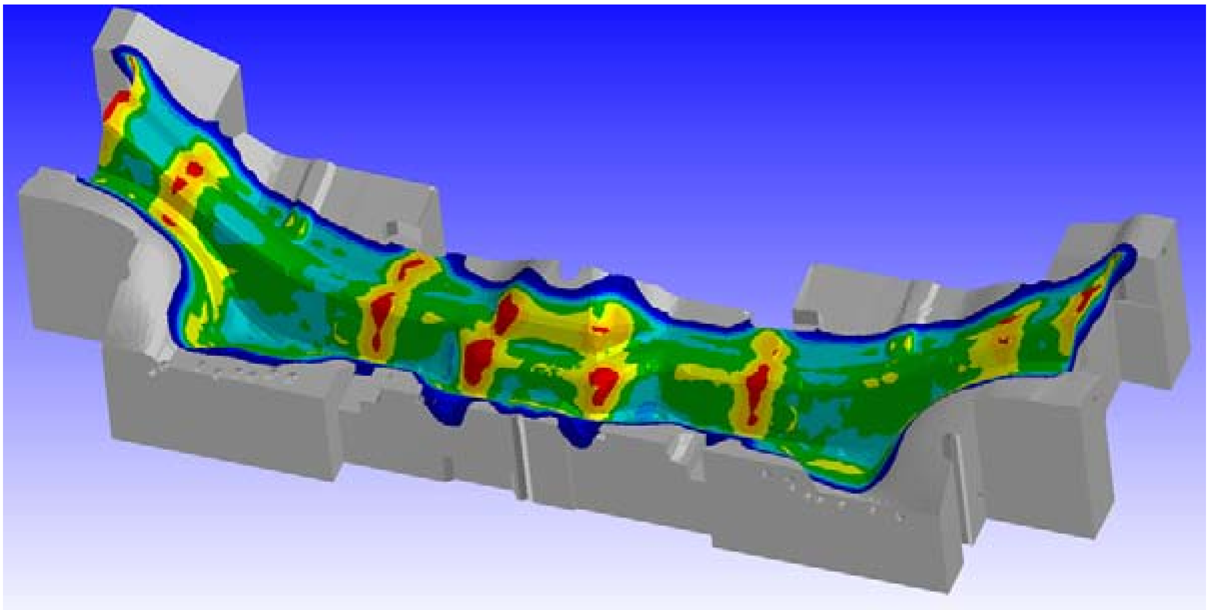

Fig. 12: Die face temperature after a few cycles – initial design with temperature peaks. The final design does not show those peaks any more.

VIRTUAL REALITY

Virtual Reality is used to review the complete engineering of hot forming lines. The major parts of a hot forming line are embedded into a virtual factory. The usage of this VR System (IC.IDO, ESI) enables reviewing the whole process sequence by flying through the press hardening line. It allows seeing potential error sources and sequence failures. It is even possible to integrate results computed with sheet metal forming simulation. For complex projects it is worth using IC.IDO to be able to reduce the lead time.

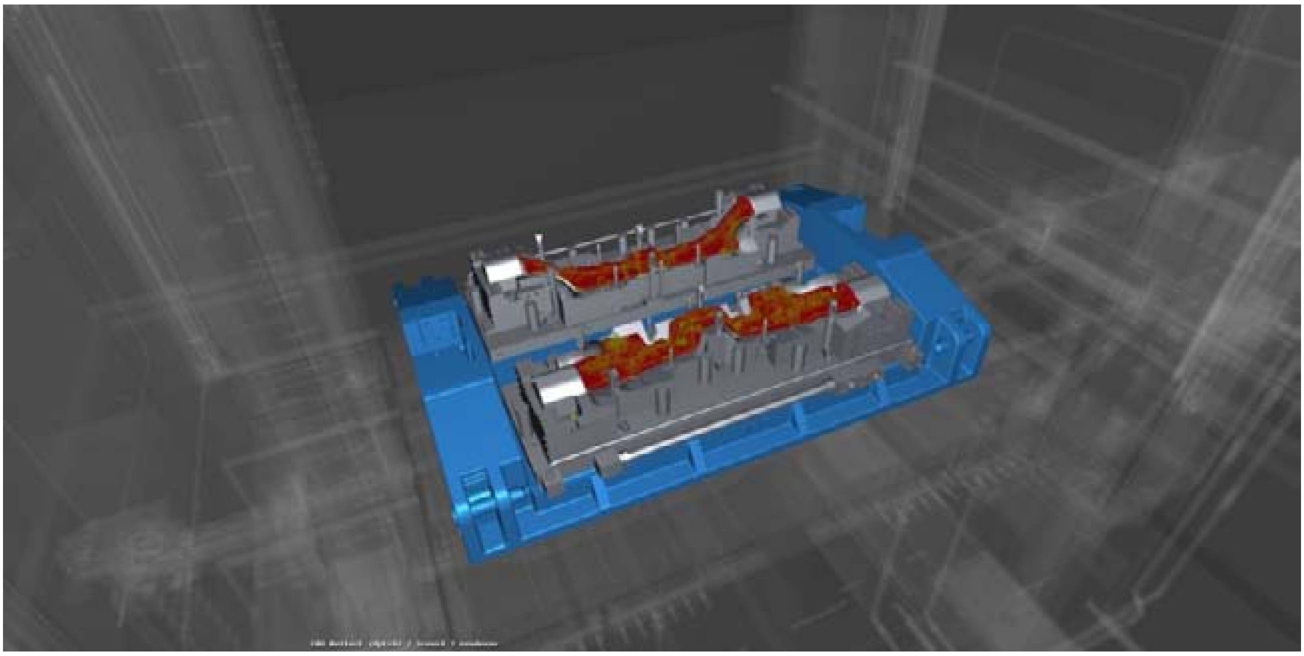

Fig. 13: Blank temperature displayed in the production line in the virtual reality system IC.IDO

AROUND THE WORLD

ESI Group
Headquarters
100-102 Avenue de Suffren
75015 Paris
France
T. +33 (0)1 53 65 14 14
F. +33 (0)1 53 65 14 12

EUROPE

BENELUX & SCANDINAVIA

ESI Group Netherlands
Radex Innovation Centre
room 4.57
Rotterdamseweg 183 C
2629 HD Delft
The Netherlands
T. +31 (0)15 2682501
F. +31 (0)15 2682514

CZECH REPUBLIC & EASTERN EUROPE

MECAS ESI
Brojova 2113/16
326 00 Pilsen
Czech Republic
T. +420 377 432 931
F. +420 377 432 930

FRANCE

ESI France
Headquarters
Parc d'Affaires Silic
99, rue des Solets - BP 80112
94513 Rungis Cedex - France
T. +33 (0)1 49 78 28 00
F. +33 (0)1 46 87 72 02

ESI France
Le Récamier
70, rue Robert
69458 Lyon Cedex 06
France
T. +33 (0)4 78 14 12 00
F. +33 (0)4 78 14 12 01

SPAIN

ESI Group Hispania
Headquarters
Parque Empresarial Arroyo de la Vega
C/ Francisca Delgado, 11.
Planta 3ª - 28108 Alcobendas
Madrid - Spain
T. +34 91 484 02 56
F. +34 91 484 02 55

ESI Group Hispania, S.L.
C/ Balmes, 188
Oficinas B188
08006 - Barcelona
Spain
T. +34 93 152 10 25
F. +34 93 218 01 01

GERMANY

ESI GmbH
Headquarters
Siemensstr. 12
63263 Neu-Isenburg
Germany
T.+49 6102 2067 - 0
F.+49 6102 2067 - 111

ESI GmbH
Einsteinring 24 - Haus 4
85609 München-Dornach
Germany
T. +49 89 45 10 888 0
F. +49 89 45 10 888 18

ESI GmbH
Kruppstr. 82-100 / ETEC
V5-105
45145 Essen
Germany
T. +49 (0)201 125 072 0
F. +49 (0)201 125 072 24

ESI GmbH
Jurastr. 8,
70565 Stuttgart
Germany
T. +49 (0) 711 27 303 0
F. +49 (0) 711 27 303 110

ITALY

ESI Italia
Via San Donato 191
40127 Bologna
Italy
T. +39 0516335577
T. +39 0516335578
F. +39 0516335601

SWEDEN

Efield ESI
Sjöängsvägen 15
SE-192 72 Sollentuna
Sweden
T. +46 8 410 03 511
M. +46 70 999 18 71

SWITZERLAND

Calcom ESI
Parc Scientifique EPFL / PSE-A
CH-1015 Lausanne
Switzerland
T. +41 21 693 2918
F. +41 21 693 4740

UNITED KINGDOM

ESI UK
16 Morston Court,
Kingswood Lakeside,
Cannock, WS11 8JB
United Kingdom
T +44 (0) 1543397900
F +44 (0) 1543504898

ASIA

CHINA

ESI China
Unit 1006-1008,
Metropolis Tower
No. 2 Haidiandongsanjie,
Haidian District,
Beijing, 100080 - China
T. +86 (10)-65544907/8/9
F. +86 (10)-65544911

INDIA

ESI India
Headquarters
No. 24-25, Ground floor
27th Cross Banashankri
2nd stage
Bangalore 560 070
India
T. +91 80 4017 4747
F. +91 80 4017 4705

ESI MW India
502, Pentagon 2,
Magarpatta City
Pune - 411 013
Maharashtra
India
T. +91-20-26898
172/173/175/229
F. +91-20-26898 239

JAPAN

ESI Japan
Headquarters
15F and 16F Shinjuku Green Tower Bldg, 6-14-1,
Nishi-Shinjuku
Shinjuku-ku, Tokyo 160-0023
Japan
T. +81 3 6381 8490 / 8494
F. +81 3 6381 8488 / 8489

ESI Japan
Kansai Branch Office
Nishi-Nihon Sales office
5F Advance Esaka Bldg,
8-10 Toyotsu-cho
Suita-shi,
Osaka 564-0051
Japan
T. +81 6 6330 2720
F. +81 6 6330 2740

ESI Japan
Chubu Branch Office
9F Daisan Horiuchi Bldg.
4-6-23, Meieki
Nakamura-ku, Nagoya-shi,
Aichi 450-0002
Japan
T. +81 52 589 7100
F. +81 52 589 7001

RUSSIA

ESI Russia
Vainera str. 51b, 3rd floor
620014, Yekaterinburg
Russian Federation
C. +7 919 361 14 80
T./F. +7 343 311 02 33

SOUTH-EAST ASIA

ESI Group
South-East Asia
ROAP Office
N° 20-2 (2nd floor)
Jalan Metro Pudu
Fraser Business Park
55100 Kuala Lumpur,
Malaysia
T. +6012 618 1014

SOUTH KOREA

Hankook ESI
4F Ryuhsan B/D, 134-1
Gayang-dong,Gangseo-gu
Seoul 157-801
South Korea
T. +82 2 3660 4500
F. +82 2 3662 0084

AMERICAS

USA

ESI North America
Headquarters
32605 W 12 Mile Road,
Suite 350,
Farmington Hills,
MI 48334-3379
USA
T. +1 (248) 381-8040
F. +1 (248) 381-8998

ESI North America
12555 High Bluff Drive
Suite 250
San Diego, CA 92130
USA
T. +1 (858) 350 0057
F. +1 (858) 350 8328

ESI North America
2880 Zanker Road
Suite 105
San Jose, CA 95134
USA
T. +1 (408) 824 1212
F. +1 (408) 824 1216

ESI North America
6767 Old Madison Pike
Suite 600
Huntsville, AL 35806
USA
T. +1 (256) 713-4700
F. +1 (256) 713-4799

SOUTH AMERICA

ESI South America
Av. Pedroso de Morais,
1619 cj.312
São Paulo
SP CEP 05419-001
Brazil
T./F. +55 (011) 3031-6221

info@esi-group.com

ABOUT ESI GROUP

ESI is a pioneer and world-leading provider in Virtual Prototyping that takes into account the physics of materials. ESI boasts a unique know-how in Virtual Product Engineering, based on an integrated suite of coherent, industry-oriented applications. Addressing manufacturing industries, Virtual Product Engineering aims to replace physical prototypes by realistically simulating a product's behavior during testing, to fine-tune fabrication and assembly processes in accordance with desired product performance, and to evaluate the impact of product use under normal or accidental conditions.

ESI's solutions fit into a single collaborative and open environment for End-to-End Virtual Prototyping. These solutions are delivered using the latest technologies, including immersive Virtual Reality, to bring products to life in 3D; helping customers make the right decisions throughout product development. The company employs about 950 high-level specialists worldwide covering more than 30 countries. ESI Group is listed in compartment C of NYSE Euronext Paris.

www.esi-group.com