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Book of Abstracts

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SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 2

Impact of the process velocities on the quality of free-form bent parts

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The geometrical accuracy of the bent components as well as their surface quality are crucial parameters to evaluate the feasibility of a bent geometry in free-form bending. In the process the deformation of the part is obtained by displacing and rotating a movable bending head with respect to the fixed holder with a given relative velocity with respect to the feed velocity. High process velocities have a beneficial effect on the realisation of bending radii and angles, but induce high local solicitations on the semi-finished part, which can result in surface defects like indentations and buckles. In this work the impact of the bending head velocity as well as of the feed velocity on the bent stability and the arising of indentations is investigated.
Experimental tests with different head and feed velocity are conducted on mild, moderate and severe bent keeping the same kinematics, and the resulting bending radii, angles and surface defects are evaluated. The results allow to identify the parameters having the highest influence on the quality of bent profiles and to propose a compromise between geometrical stability and surface quality.

Speaker Country:

ADDITIVE MANUFACTURING / 3

Improving the performance and reparability of forming and cutting tools by additive manufacturing

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The edges and corners in the cavity of the forming and cutting tools are the most worn parts of the tools. These areas are the potential to be made and repaired by Additive Manufacturing mainly by DED (Directed Energy Deposition) using materials with superior thermo-mechanical properties in contrast to ordinary materials used for tool bodies. The normal ordinary material which is cheap will be used for the base structure and hard and abrasive–resistant layers, more expensive, will be used for the highly stressed area. The intermediate layers will be used to improve fatigue resistance. The DED process is most practical for such an approach since the process allows to use of different materials in each layer. In this study, the DED process is used to develop a high-performance trimming die.
The FEM analysis was used to evaluate the shear stresses to optimize the cutting tool shape and deposited area.
Several experiments will be performed to validate.

Speaker Country:

TESTING, TESTBEDS / 4

Innovative experimental setup for the investigation of material models with regard to strain hardening behavior

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Sheet metal formed parts are often produced in multistage processes. The multi-directional deformations that occur in this process pose a challenge for sufficiently accurate modeling of the material behavior. In this paper, we present an experimental methodology and its potential that serves as a basis for a comprehensive validation of material models with respect to multi-directional deformation. Therefore, we present the experimental results of pre-strained DP600 specimens, which we afterwards subjected by the MUC Test. The MUC Test has already been established as a methodology for validating material models under proportional loading. By using pre-strained specimens, this methodology can be extended to non-linearities in the load history. For the purpose of the paper, we pre-strain the sheet material in three conditions: uniaxial tension, plane strain and equibiaxial tension. Thus, we show that the MUC Test is suitable for the representation of multi-directional strain histories and useful for comprehensive validation of material models.

TOOLS AND DIES / 5

Dimensional precision and wear of a new approach for prototype tooling in deep drawing

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In this work, we present and evaluate a new approach for prototype tooling in deep drawing based on direct polymer additive tooling. With Fused Deposition Modeling (FDM) a PLA shell is printed additively. Afterwards, these are filled with ultra-high performance concrete (UHPC). UHPC is characterized by its higher strength properties compared to conventional concrete materials, which makes the material feasible for forming applications. This hybrid UHPC polymer additive tooling has the potential to be more cost-efficient for small series and is more resilient than entirely additively manufactured polymer tools.
The dimensional precision and wear of such hybrid tools is evaluated using a standard cup geometry. A test series with sheet metal DX56 with 1 mm thickness was drawn with the prototype tool as well as a conventional steel tool. The dimensional precision of the drawn parts were analyzed using an optical measuring system. Additionally, the wear of the prototype tool was evaluated optically as well as tactilely.

Speaker Country:

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 6

Carburization behavior at elevated temperatures and mechanical properties of a hot stamped complex phase steel

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As a lightweight construction strategy, hot stamped parts of ultra-high-strength steels with tailored properties are increasingly used for crash relevant components in car bodies, e.g. as B-pillars. With the process of tailored carburization, parts can be reinforced locally without increasing the sheet metal thickness. Thus, this process has the potential to be applied to lightweight components for no deformation zones, e.g. in the battery housings. Standardly, carburization is performed at 950°C, with the highest strengths achieved at long times of up to 6 h, which prolongs the total process time. By raising the temperature, the carbon diffusion increases, which enables a reduced heat treatment time and, consequently, a shorter process time. Therefore, the objective of this study is to investigate the influence of elevated carburization temperatures on the mechanical properties of a carburized and hardened complex phase steel, CP W® 800. A single carburization step at the enhanced temperatures leads to an embrittlement of the samples. Hence, an additional diffusion-annealing step is implemented to homogenize the carbon content, without enlarging the total heat treatment time. Depending on the time allocation of carburization and diffusion, the application of the diffusion annealing step results in higher strengths and ductility compared to only carburized samples.

SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 8

Study of the Influence of part features of AHSS A-pillar on springback and its robustness

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In this paper, the AUTOFORM stamping simulation software is used to analyze the formability and springback of A pillar part, and the influence of part features on springback and its robustness was studied. The results show that when stamped with the third generation advanced high strength steel QP1180, the maximum local thinning rate of the part is 0.157 without cracking risk. And the maximum springback value is negative 9.58mm at the part end while the value is positive 3.54mm in the middle area. In addition, the A pillar part can be decomposed into straight sections and arc sections along the longitudinal, and the springback of this two sections are analyzed separately, where it can be seen that the twisted springback mainly appears in the arc section while the springback at the linear section is small, and the main reason for the overall distortion comes from the arc section. After adding features through the angular edges along the longitudinal direction, the maximum springback at the part end drops from 5.522mm to 1.664mm, and the maximum springback in the middle drops from 2.365mm to 0.939mm. The robustness analysis of this part considering the material yield strength, tensile strength, plastic strain ratio, compression force, friction coefficient and other process parameters around 10% were also analyzed, the results show that the maximum springback is strongly related to material yield strength, and the robustness is improved greatly after adding part features. It can be used as an effective measure to improve the mass production of ultra high strength steel parts due to material performance fluctuations.

FORMABILITY / 9

Formulation of the eMMFC failure criterion assuming a non-associated flow rule

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The experimentally recorded FLC are valid only for linear strain paths. A non-linear strain path history but also different sheet thickness to radius of curvature ratios t/r can strongly shift the position of the linear FLC.
In order to correctly account for these effects in the simulation, a numerical prediction of the instantaneous FLC is required. Beside of the M-K model, the Modified Maximum Force Criterion eMMFC offers a numerical approach for calculating the FLCs.
The eMMFC criterion [Hora et al, 2016] strongly depends on the rate at which the stress state changes during evolving localization. This dependence is expressed in the eMMFC criterion by the term (∂σ/∂β ∂β/∂ε), where β is the strain ratio ⊠Δε⊠_²²⁄⊠Δε⊠_11 . In particular, the first term ∂σ/∂β depends to a strong extent on the shape of the yield locus.
Investigations on aluminum materials, which are often described with the non-quadratic yield loci according to Barlat YLD2000 models with m = 8, show a too low level of the FLC curve in the right β≥0 FLC section. In contrast, models which assume a lower m value provide FLC levels with much better accordance the experimental values.
In order to more accurately represent this behavior, which is particularly observed for Al materials, the eMMFC criterion is extended by the option of a non-associated flow rule for evaluating the dependence (∂σ/∂β ∂β/∂ε).
The accuracy of the FLC determined in this way is compared with experimental FLC's for different 6xxx and 5xxx Al alloys.

Hora P., Tong L., Manopulo N.: Theoretical prediction of FLC based on curvature and strain rate dependent MMFC criterions. Proceedings of IDDRG 2016.

LIGHTWEIGHT STRUCTURES / 10

Development of a novel in-situ measurement method for thermo-mechanically coupled material characterization of high-strength aluminum alloys

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High-strength aluminum alloys are more and more used for safety and crash-relevant components due to their advantageous density-to-strength ratio. By using thermal-supported forming strategies, failure-free deep drawing is possible for these materials. In this context, the hot form quench process (HFQ®) has shown to be a promising thermally-assisted forming strategy. By using locally tempered forming tools, the production of tailored components with different mechanical properties is possible. However, material characterization and process design with conventional characterization methods are quite challenging. A new approach is the use of ultrasound-assisted material characterization in combination with a thermo-mechanical simulator. Thereby it is possible to perform an in-situ material characterization. However, this technology is mainly used for steel materials. In this contribution, the potential of an adapted measurement strategy for high-strength aluminum alloys is presented. For this purpose, the influence of different measurement parameters on modified samples and the resulting measurement signal is investigated. With the help of this study, new standards are set for time-bound material characterization under thermo-mechanical stress. As a result, thermally-assisted forming methods can be designed more efficiently and faster in the future.

SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 11

Process optimization and robustness analysis for HFQ process using AutoForm-Sigma

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Lightweight materials and lightweight technologies gained significant attention from all EV vehicle manufacturers. Aluminium has been commonly used as a lightweight replacement for steel in the automotive industry for many years. High-strength aluminium alloys have high specific strength, and their formability increases significantly at elevated temperatures. New manufacturing technologies incorporating elevated temperature forming have emerged recently, allowing forming of high and ultrahigh-strength aluminium alloys. One such technology is HFQ® which is a process that combines high formability with virtually no springback for (ultra)-high-strength aluminium alloys. The thermal expansion of aluminium alloys is approximately twice that of steel, leading to significant material contraction during in-die quenching. This is especially pronounced for large or long components. Therefore, robustness analysis of the process parameters can be used to optimise the process parameters and enable a capable production of parts meeting dimensional specification requirements. Such analysis can be performed using AutoForm-Sigma solver and this paper presents a simulation methodology developed in AutoForm and its use to verify the accuracy of the thermal distortion prediction for one of the safety cell structure components. Sigma simulation has been implemented to optimise the process parameters to improve manufacturing robustness.

FOSSIL-FREE STEEL, SUSTAINABLE MATERIALS, AND MATERIAL FORMING / 12

Strength enhancement and uniform grain refinement through cross route-constrained groove pressing

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Constrained groove pressing (CGP) is one of the severe plastic deformation techniques for sheet metals to impose large plastic strain and produce ultrafine-grained (UFG) structures without any change in dimensions. Cross route-constrained groove pressing (Cross-CGP), an advanced version of the conventional CGP process, involves two CGP cycles with an equivalent strain of 2.32 per cycle where the square sample is rotated by 90^0 after performing every cycle of CGP. The strain path in the sheet during Conventional CGP and Cross-CGP significantly affects the homogenization of mechanical properties. Two sheets of non-ferrous alloys are initially processed through both routes and then microforming is performed on the UFG sheets. The ability to sustain the maximum strain has been increased in the Cross-CGP process due to uniform strain distribution. The results showed that the tensile strength and hardness in the sheet processed through Cross-CGP are higher than that of Conventional CGP, especially at higher pass numbers. Tensile behavior and hardness in two different orientations (parallel and perpendicular to the groove direction) have been found to be almost the same in the Cross-CGP processed sheet. Moreover high geometrical accuracy is observed in UFG sheets.

FORMABILITY / 13

Local and global forming potential of present dual-phase steel developments

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Modern car bodies are constantly relying higher proportions of high and ultra-high strength steels. In the past, the increase in material strengths led to a conflict regarding the complexity of component geometries. Limits of material formability were reached and compromises had to be made in part design. By integrating application-oriented problems into the material development, these limits are expanded with respect to the given requirements. Within the present study, for several dual-phase steels with a tensile strength ≥ 800 MPa, practical laboratory tests are presented and their benefits in press shop application. In particular influencing factors on stretch flange formability are presented and discussed for example cutting parameters, anisotropy, time between cutting and forming or the orthogonal strain gradient.

FORMABILITY / 14

Numerical and experimental investigation of hole flangeability of AA6061 alloy

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Aluminum alloys are being used extensively in the automotive industry to meet the increasing requirements for light weighting. The remarkable strength to weight ratio offered by aluminum alloys combined with good formability makes them suitable for manufacturing of light weight vehicles. Aluminum alloys of 5xxx and 6xxx series are particularly more important for applications in automotive and aviation industries in which formability of sheet metals is critical. Edge formability is a measure of local formability and it is important for forming processes like stretch flanging. Hole flangeability of sheet metals is evaluated by determination of hole expansion ratio (HER) using a standard hole expansion test (HET). In the present work, numerical and experimental investigation of hole flangeability has been carried out on 1.6mm thick AA6061 alloy sheets. Numerical simulations have been carried out using two different work hardening laws (Swift and Voce). Failure prediction has been made using experimentally determined forming limit curve of AA6061 alloy sheets. HER and thickness have been predicted along the edge of the expanded hole by simulation. The maximum thinning has also been predicted analytically incorporating anisotropy. The predicted HER and thinning from analytical and FE simulation have been validated experimentally by performing hole expansion tests according to ISO 16630-2009 using a conical punch. The predicted results have been found out to be in a reasonably good agreement with the experimental results.

TESTING, TESTBEDS / 15

Effect of temperature, sliding velocity and sliding distance on friction during hot stamping process

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Formability under hot stamping process depends on various process parameters and tribological conditions. Friction is one of the critical parameter for better understanding of formability at elevated temperatures. It was found that with increase in the temperature friction coefficient increases, however in some literature it is reported that with increase in temperature friction coefficient decrease. Therefore, in this study effect of temperature, sliding distance and sliding velocity on coefficient of friction is analysed using Bending Under Tension test (BUT). To conduct experiment L27 Taguchi array with input parameters of temperatures, sliding distances and velocities were used. It was observed that with increase in temperature, sliding velocity, and sliding distance coefficient of friction increases. ANOVA method was used to analysis the influence of process variables on friction coefficient measurement, and also interaction between each process variable. It was found from ANOVA analysis that temperature was most significant parameter to effect friction coefficient.

TOOLS AND DIES / 16

Proposal of a new tool for pre-straining operations of sheet metals

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With the increased focus on reducing carbon emissions in the automotive industry, more advanced materials are introduced to reduce the vehicle weight, and more complex component geometries are designed to both satisfy customer demands and to optimize the vehicle aerodynamically. With the increase in component complexity, the strain paths produced during the forming operation of car body components often display a highly non-linear behavior which makes the task of failure prediction during the manufacturing feasibility studies more difficult. Therefore, CAE engineers need better capabilities to predict failure induced by strain path nonlinearity.
In order to develop these capabilities however, an experimental setup that can generate non-linear strain paths is needed. This study proposes a new simple tool design for the pre-straining of sheet metal in the three main loading directions – uniaxial, plane strain, and biaxial. The tool is designed to allow for subsequent Nakajima testing with a reasonable uniform strain distribution in a circular area Ø200 [mm] allowing for full-sized Nakajima specimens to be blanked out of the deformed specimen. From the blanked Ø200 [mm] specimen, further blanking operations can be performed to reduce the width of the Nakajima specimen to obtain all needed directions for the characterization of the pre-strained Forming Limit Curve, or reproduce critical strain paths i.e. strain paths direction changes with respect to the rolling direction of the sheet.

Speaker Country:

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 17

Simulation of deep drawing of dual phase steel sheets incorporating tribological behaviour predicted by advanced friction modelling

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In a deep drawing process, the friction at the sheet metal-die contact interface affects the material flow in the flange as well as in die entry radius region, affecting product quality significantly. The accuracy of predicted drawing force and thinning in deep drawing simulation strongly depends on friction modelling. The Coulomb's friction model with a constant coefficient of friction is generally assumed in simulations. In reality, the actual friction coefficient depends on process variables such as local contact pressure, relative sliding velocity, and strain in the sheet material. In this work, an approach is presented for friction modelling in deep drawing simulations of dual phase (DP600) steel sheets. In order to account for variation in friction coefficient, the TriboForm plugin is used in combination with AutoForm software. The predicted friction coefficients are verified using the data from standard strip drawing friction tests under conditions similar to that exist in the flange area during deep drawing. The experimental and simulation results of the friction coefficient show a good overall agreement. Deep drawing simulations have been performed considering Coulomb's model and Triboform friction model. The simulation results are validated using deep drawing experiments. It is concluded that the numerical prediction of the punch force, strain distribution and percentage thinning is highly sensitive to friction. In addition to an overall improvement of the predictive accuracy of deep drawing simulations by friction modelling, the effect of varying frictional conditions can be incorporated into deep drawing simulations using this approach.

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 18

Analysis of process limits for partial hot stamping with controlled pre-cooling by radiation exchange

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The increasing demands on part complexity and tailored properties in form of local strength and ductility cannot be met with a conventionally manufactured hot-stamped body part. In order to meet the requirements of safety-relevant body parts, partial hot stamping is increasingly used in the industry. One approach to achieve tailored properties on hot-stamped parts is based on controlled cooling of the blank prior to forming and quenching. The related furnace technology is based on a special chamber in which a cooled aluminum mask protects local areas of the blank from thermal radiation and at the same time absorbs the blank's own radiation. The use of different sheet thicknesses and materials can influence the controlled radiation exchange and can lead to lower process limits. In order to analyse these process limits, blanks made of the materials 22MnB5 AS150 and 8MnB7 AS150 are partially pre-cooled in different sheet thicknesses and then hot-stamped. In addition, the process is simulated with AutoFormR10® and validated by the experimental results obtained. The results show that the sheet thickness is a key influencing factor in the process and significantly affects the mechanical properties after partial hot stamping. Especially with sheet thicknesses ≥ 2 mm, the effectiveness of the radiation exchange for controlled pre-cooling and phase transformation is limited.

FORMABILITY / 19

Investigation on rubber forming of high strength aluminum alloy at elevated temperature

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Rubber forming is a flexible forming technology which have widely application on low volume sheet metal forming process. However most of the investigation focus on forming process at room temperature due to the equipment limitation. In this paper a rubber forming system was built which include a die heating system and heat resistant rubber. The blank and die can be heated to a high temperature, and rubber pad can be kept in a room temperature. The formability on rubber forming at elevated temperature of a high-strength aluminum alloy AA20204 is invested through experiment. Deep drawing, flange and bulge ability of AA2024 were invested at 150-350℃. Three experiment condition were set. Fist a non-isothermal process which with hot blank and cold die and rubber during the forming process. Second the blank and metal die both were heated to a high temperature and the rubber pad keep at room temperature. Results shows that formability could be effective improved after the temperature higher than 180℃. The method which only blank is heated to high temperature with cold rubber and die is feasible. The microstructure and property of the formed parts were also invested through experiment.

SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 20

Measurement of skid line formation and formation mechanism of automotive outer panel

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Appearance of an automobile is one of the appealing points to customers. Character lines in outer panels such as hood and door panels play an important role to make automobiles attractive, and a sharp character line which has a ridge of small curvature radius is much more preferred to a blunt character line. However, a skid line, a kind of appearance defect, is apt to generate along the character line in press forming of a sharp character line. Although it is well-known that skid lines are caused by inhomogeneous tension, the mechanism of skid line generation was not yet fully understood. In this study, the skid line defect is quantitatively evaluated by a draw forming experiment using a newly devised die which can continuously measure a panel shape during press forming. The mechanism of skid line formation was clarified by the experimental results. The results of the shape measurement suggest that a convex shape formed on the die ridge should move to a flat area of the die. A wavy shape should be generated there immediately before the convex shape is flattened at the bottom dead center of the die. Then the wavy shape should grow to a skid line through springback.

Speaker Country:

TOOLS AND DIES / 21

Investigation of tool damage in shear cutting of ultra high strength sheet steels

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Proportions of high- and ultra-high strength steels are constantly increasing in modern car bodies. In the press shop there are uncertainties concerning the application of steels with strength higher than 1000MPa particularly concerning shear cutting processes. To support the steel user regarding a tool material and coating and the wear behavior, long-term shear cutting test had been carried out. The effects of various shear cutting conditions on tool damage were investigated by continuous shear cutting test with an amount of cutting shots up to 100,000 times. Tested sheet materials were 780, 1180 and 1470MPa grade steels. The changed cutting conditions were sheet steel strength, tool material, cutting clearance, and rake angle. Measurements by laser and confocal microscopes were carried out in order to reveal tool damage mechanisms. The features of tool damage were classified as wear, chipping, and plastic deformation. The amount of plastic deformation rises with the increase of sheet steel strength. Not only plastic deformation but also chipping in the tested tool was observed in the cutting test of 1180MPa sheet steel by standard tool steel (DIN 1.2379) after 40,000 shots. Large plastic deformation in the tested tool was observed in a cutting test of 1470MPa sheet steel by high speed steel (DIN 1.3343) after 100,000 shots although no chipping was detected. Under a rake angle of 5 degree, serious chipping and tool wear were observed especially near the final sheet-tool contact position. Regarding clearance, the amount of plastic tool deformation increased with the decrease of the clearance. This effect of the clearance can be explained by vertical force and by sheet rotation during cutting.

DIGITAL TRANSFORMATION, DIGITALIZATION, SMART PLANTS, SMART PRESSHOPS / 22

Industrial Internet of Things and Big Data Techniques for the Smart Press Shop 4.0 Development in Automotive Industry

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Keywords: Digital Transformation, Real Time, IIoT, Digital Sensor, Industry 4.0

ABSTRACT

In recent years, one of the main challenges in industry has been obtaining work parameters in real time for later analysis to understand the process better. The purpose is to obtain substantial information about the process for better decision-making, i.e., what happens during manufacturing to know both the state of the equipment and the product, looking for savings in maintenance costs and quality controls among others. In automotive industry it has not been an exception. These challenges have been associated with the concept of Industry 4.0, specifically with Big Data and IIoT (Industrial Internet of Things) techniques. In this line, a multitude of applications have been proposed and developed, see [1]. The main problem comes during the implementation in the industry since the need

to introduce sensors in each one of the machines, to wire it, etc., supposes a very high cost that in some cases minimizes its implementation to critical machines.
To develop this technology in a massive way in one of our previous works [2] a new concept was proposed, using the information available in the PLCs to carry out a low-cost Big Data project. In [2] a standard called Miniterm was developed, which proposes to measure the actuation time of a mechanical component connected to a PLC, as a virtual sensor to measure the deterioration of the components without the need to install the sensors proposed in the literature such as ultrasound. This standard is being adopted by Ford Motor Company where there are currently more than 22,000 Miniterms installed in different Ford Europe factories.
In the press shop where the stamping machines are equipped with many sensors, we have this information available in the PLC. Therefore, a new criterion based on Miniterms called Criterion-360 has been developed. This criterion allows us to obtain working parameters of the presses in each cycle. For each degree of rotation of the main axis of the press, data from sensors is stored in the PLC, then the data block is sent through the industrial network to the office network and stored in a database. Tonnage information carried out by the press, the pressure and position of the cushion, the compensation pressure and the press speed are currently being monitored. This methodology allows us to access the data in each cycle from any device in real time.
With this database at our disposal, many possibilities for the development of new applications and tools are opened towards what has been called "Smart Press Shop 4.0". In our previous works, we have begun to explore different possibilities, such as being able to predict the failure of the press, [3], energy savings in the plant [4], or beginning to move towards a digital twin of the stamping process [5]. This article aims to define the concept of "Smart Press Shop 4.0" through the Criterion-360 for the development of viable industrial Big Data of the stamping process, exploring new measurables and possible applications.

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FOSSIL-FREE STEEL, SUSTAINABLE MATERIALS, AND MATERIAL FORMING / 23

Evaluation of hole expansion ratio of ultra-high strength martensitic steels produced with various processing routes

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Hole expansion ratio of ultra-high strength martensitic steels with tensile strength around 1000 MPa was evaluated. Steels were produced with direct quenching and traditional reheat and quenching processes with final thickness of 3 mm. Achieved yield strength values (Rp0.2) varied between 918 – 1068 MPa depending on the processing route. Mean hole expansion ratios (HER) in direct-quenched

(DQ) and direct-quenched and tempered (DQT) conditions were between 22 – 36 %, and no clear improvement was seen after tempering treatment compared to quenched variant. HER values for reheat and quenched (RQ) and reheat, quenched and tempered (RQT) variants were between 31 – 49 %, and the highest values were achieved with RQT steels, which were tempered at 600 ℃. Based on the field emission scanning electron microscope with electron backscatter scanning diffraction (FESEM-EBSD) analysis/characterization of martensite grain size, more uniform grain structure was discovered in RQ steels, which could be the reason for improved HER properties. HER values were also compared to tensile test results (uniform elongation, true fracture strain), and formability maps were constructed. However, only minor correlation were found between HER and true fracture strain values.

Speaker Country:

FORMABILITY / 24

Study on the ultrasonic-assisted spinning-extrusion forming of thin-walled cylindrical parts with vertical and horizontal ribs

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Abstract: The thin-walled cylindrical parts with ribs, as the main structure of the launch vehicle, has been currently used in block manufacturing mode, which has the disadvantages of long manufacturing cycle, low material utilization rate and limited structural lightweight. Therefore, the integral forming process of the thin-walled cylindrical parts with ribs is an inevitable development trend. At the same time, studies have shown that the application of composite energy fields in the plastic forming process can help reduce the forming load and promote material flow. In this paper, a new method of ultrasonic-assisted spinning-extrusion integral forming for thin-walled cylindrical parts with outer ribs was proposed, which could not only improve the manufacturing efficiency of ribbed cylindrical parts, but also further improve the forming height and uniformity of outer ribs. A simulation model of ultrasonic-assisted spinning-extrusion for thin-walled cylindrical parts with vertical and horizontal outer ribs was established, the influence of ultrasonic amplitude on the forming accuracy of vertical and horizontal outer ribs was obtained, and the mechanism of ultrasonic vibration improving the forming accuracy of vertical and horizontal outer ribs was revealed. On this basis, ultrasonic-assisted spinning-extrusion equipment was built to verify the feasibility of this process. The results showed that with the increase of ultrasonic amplitude, the forming height of vertical and horizontal outer ribs gradually increases, and the effect of raising the forming height of longitudinal ribs is higher than that of transverse ribs. In addition, the introduction of ultrasound improves the filling of materials. As the ultrasonic amplitude increases, the uniformity of the forming morphology of the outer rib is also improved. The spinning-extrusion of the outer rib is mainly realized by the material flow in the tangential and radial directions. The ultrasonic vibration improves the material flow properties in these two directions, and promotes the filling of the material into the rib groove, thereby increasing the spinning-extrusion forming accuracy of the outer rib. The forming height of the outer rib was measured with or without ultrasonic vibration. When the rolling reduction is 1 mm, the average forming height of the outer rib with ultrasonic amplitude of 9μm is nearly double that of the outer rib without ultrasound, which provides a new research idea for the integral forming of the spinning-extrusion of thin-walled cylindrical parts with vertical and horizontal ribs.

FORMABILITY / 25

An evaluation method for experimental necking detection of automotive sheet metals

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In sheet metal stamping, the occurrence of strain localization in a deformed sheet is considered the failure. As so, the formability of a sheet metal is conventionally evaluated by using the forming limit diagram. This study presents an evaluation method for detecting the strain localization during experiment based on the digital image correlation. The strain-field distribution on the surface of the deformed specimens is captured by a commercial software ARAMIS. A detail analysis of the proposed method is presented considering uniaxial tensile and Nakazima tests conducted for two automotive sheet metals AA6016 and DP800. Compared to the ISO standard method, the proposed method presents lower forming limits for both investigated materials.

DIGITAL TRANSFORMATION, DIGITALIZATION, SMART PLANTS, SMART PRESSHOPS / 26

Innovative draw-in measurement solutions for the intelligent control of stamping processes

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Production tolerances and specifications are increasingly being tightened by OEMs and final user in the metal stamping sector. For this reasons, intelligent controllers that can modify the process to obtain a stable production considering the most influencing process fluctuations are more and more demanded. The generation of metamodels using numerical simulation and their use in modern model-based controllers is one of the recent approaches to deal with the high non-linearity of the metal forming processes. The metamodel adds the needed explainability to the controller while the continuous recalibration of the governing models using production data improves the accuracy of the controller to obtain a reliable control system.
In all the new controllers, the draw-in and temperature measurements are considered to be precise inputs for the calculation of the new process parameters. Although laser triangulation sensors are being used at laboratory or preindustrial applications, their cost and robustness is not sufficient and they cannot work in combination with non-flat blank holders.
In the present paper a new cost effective and tactile draw-in measurement sensor is presented and validated using a laboratory demonstrator. Moreover, a new sensor, based on backlight technology is presented for the full contour measurement after stamping. Both inventions are the perfect combination for the initial tool set-up and for the process monitoring during industrial production.

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ADVANCED/SMART MATERIALS, BIPOLAR PLATES, AND MULTI-MATERIAL CONCEPTS/SOLUTIONS / 27

Development of a mechanical joining procedure for hybrid aluminum and carbon fiber reinforced polymer components

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The joints between different lightweight materials play a significant role in multi-material design of structural components for automotive industry, aiming to reduce the vehicle's weight without compromising performance or safety. Yet, conventional mechanical joining technologies between metals and Carbon Fibre Reinforced Polymers (CFRP) either create the need of drilling a hole in the composite material, leading to damages which reduce the load bearing capacity, or increase the weight of the part due the incorporation of fasteners. At the same time, alternative mechanical joining methodologies involve complex and costly processing, hindering their industrial application.

In this work, a new mechanical joining strategy between aluminum and CFRP was developed and characterized. Such technology combines loads and deformations involved in both materials during cold forming processes to generate strong joints. The procedure can be easily integrated in traditional sheet metal forming steps, which makes it simple, cost-efficient, and easy to implement in large production series. At the same time, it avoids the incorporation of fasteners, the drilling or damaging of the composite material and complex processing.

The process is currently under a patent evaluation. The patent will be sent along December. Therefore, we cannot disclose more detailed information and this text contains the information we can submit at the moment. We know the information provided in the abstract is vague, but we will prepare a sound paper when we get the green light from our legal department. We will be glad to show our results for the first time in the IDDRG conference.

LIGHTWEIGHT STRUCTURES / 28

Performance of stringer sheet parts under dynamic load

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The stringer sheet forming process chain enables the cost-effective production of components with significantly increased stiffness for mass markets such as the automotive sector. In the first process step, a stringer is added to a conventional sheet by laser welding. In the subsequent process step, the stringer sheet parts are formed by a deep drawing operation. Previous investigations of component performance focused in particular on the static stiffness of the stringer sheets. The behavior under dynamic load, such as in crash events, has not been systematically investigated to date. This study characterizes the crash performance of stringer sheet components by means of a drop hammer test. First, the boundary conditions for the experiment are determined via numerical simulations. The energy absorption of the components is evaluated in the experiment based on the rebound height of the drop hammer, whereas the structural integrity is characterized based on the maximum dynamic as well as permanent deformation. The components are varied fully factorially with respect to the parameters stringer height, stringer thickness, thickness in the base sheet and the height profile of the stringer. In addition, spot sample tests are carried out for additional parameters mainly derived from the forming process, for example blank holder force, lubrication, and presence of a draw bead. The influence of these parameters on the energy absorption and structural integrity is assessed. Noticeable discrepancies concerning the influence of the parameters on the static behavior of the components are discussed in detail. Furthermore, the results of the numerical simulations are validated against the experimental results.

Speaker Country:

SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 29

Effect of strain mode and blank orientation on waviness and its potential improvement in paint appearance of automotive outer panels

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Paint appearance is an important requirement for outer automobile panels. Since the last decade automotive manufactures start reducing paint thickness for environment issues. As a result, the surface roughening of steel substrate due to stamping becomes a critical factor for paint appearance. Although many research work has been conducted on surface roughening, limited research has been made concerning waviness and stamping conditions in pressshop. In this work the effect of strain mode on waviness evolution has been investigated. It is found that the strain mode, biaxial stretching or plane strain tension, has significant effect on waviness. In addition, the blank orientation relative to the major strain direction also affects the waviness after forming. This documented knowledge will help automotive to optimise waviness in the pressshop.

SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 30

The influence of drawing beads on wrinkle formation in the deep-drawing process of paperboard

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The deep drawing of paperboard has shown beneficial results in the packaging industry for different goods. High productivity, economical process routes and geometrical freedom are the three most important process benefits. Paper as a material combines compostability and recyclability while being manufactured from renewable resources. However, formed paper shows wrinkling due to the material excess caused by the deep drawing process. As a consequence of the anisotropic material behavior, wrinkles form differently depending on the direction of the fibers. The current state of the art is to control this wrinkling by an additional upstream embossing step. Aiming to provide the largest possible wrinkle-free areas, while more but smaller wrinkles are formed in the corner areas. In sheet metal forming, drawing beads are used to control the material flow of asymmetric components and to adapt them to the target geometry. This paper shows how drawing beads can be transferred to paperboard forming to counteract anisotropic material behavior without the necessity of an additional process step. The design of the drawing beads regarding position and shape as well as the advantages and disadvantages will be discussed based on numerical simulations and experimental tests. Results are based on geometric mapping and measurements of wrinkle free areas. In order to extend the validity of the results, different coated and uncoated papers were considered.

It will be demonstrated how drawing beads can be used to control the position of wrinkles and increase wrinkle-free areas. Additionally, the anisotropic springback of formed paper, which results in poor geometric accuracy, can be reduced by drawing beads.

FOSSIL-FREE STEEL, SUSTAINABLE MATERIALS, AND MATERIAL FORMING / 31

Material variability effects on automotive part production process

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The decarbonization of steel sheet metal production process introduces new challenges for the automotive part production process. Especially, the recyclability component, the efforts to increase the steel scrap in the primary steel making process beyond the levels currently used, produces increased variability intervals for certain residual elements outside the levels typically found in the iron ore-based chemistry liquid steel making. The chemistry variability produces small but still detectable mechanical properties deviations of the sheet metal products like plastic work hardening, anisotropy and total elongation. In this paper a study of material variability effect on part make-ability of several automotive parts currently produced with highly formable materials are investigated. New material parameter variation intervals are generated from data variability of mild steel grades with different degrees of formability. The study shows that material variability studies of existing forming processes provide an efficient way to gain insights in material suitability in relation to forming process control challenges and potential part design limitations.

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 32

Numerical modelling of shear cutting using particle methods

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The use of Advanced High Strength Steel (AHSS) allows for lightweighting of sheet steel components, with maintained structural integrity of the part. This has enabled a wide-spread use of the materials and an ever increasing development of new, even stronger AHSS grades. However, with increased strength comes limited formability. Thus, the use of conventional cold forming processes is not always possible. Edge-cracking is a manufacturing defect common in cold forming of AHSS. It arises from damage introduced to the cut edge during the shear cutting process, prior to the cold forming steps. The edge-cracking phenomena cannot be predicted using conventional forming limit diagram. Consequently, new predictive tools are required.

Numerical modelling of the shear cutting process can aid the understanding of the sheared edge damage, thus avoiding unforeseen edge failure in the subsequent cold forming. However, the extreme deformations and rapid failure of the blank during the shear cutting process are likely to cause numerical instabilities and divergence using conventional Finite Element modelling. To overcome these challenges, this work presents the use of a particle-based numerical modelling method called the Particle Finite Element Method (PFEM). PFEM was developed for accurate handling of some of the challenges encountered in shear cutting with the standard Finite Element method, such as large deformation, angular distortions, generation of new boundaries and an efficient way of transfer historical information from the old to the new mesh, minimising the diffusion. It has in previous research also been proven suitable for orthogonal cutting with chip formation and granular material flows.

The present work shows prediction of the cut edge morphology of AHSS using a PFEM modelling scheme, where the numerical results are verified against experiments. Additionally, the work shows the benefit of using particle based numerical methods over the conventional Finite Element Method. With these results, the authors show new possibilities to obtain accurate numerical prediction of the shear cutting process, which promotes further advances in prediction of edge damaged related to shear cutting of AHSS.

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 33

Surface technology for advanced performance in high strength steel sheet forming

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It is increasingly important to optimize fabrication processes with regards to the efficient use of resources and to lower their carbon footprint. Especially for the automotive industry, these demands have increased the importance for new for lightweight construction solutions. One approach to achieve lightweight components was the introduction of new, high strength steel sheet materials for forming applications. These allowed the manufacturing of structural components with less material and to fulfill legal carbon emission and safety requirements.
To enable efficient processing of high strength steels, it is necessary to continuously evolve the design of forming tools with, for example, optimized tool materials and wear resistant coatings. The use of wear resistant physical vapor deposition (PVD) coatings has become a standard practice in many applications. For their use in forming and cutting of high strength steel which are highly demanding, one must consider the entire production chain: tool steel selection, pretreatment and PVD coating, as well as post-treatment.
To define the tool characteristics required for the forming of high strength grade materials one must first understand the application-specific wear mechanisms and possible types of tool failure. Subsequently, this knowledge can be translated into requirements for the forming tool itself and for the combined physical properties of the tool steel and the applied PVD coating, as well as additional surface pre-/post-treatments.
This talk will cover the potential performance increase that can be achieved in applications and highlight the synergistic use of tool material, tool preparation and PVD-based surface technology. Exemplary application cases will be utilized to discuss and demonstrate the impact of the different tool characteristics.

ADVANCED/SMART MATERIALS, BIPOLAR PLATES, AND MULTI-MATERIAL CONCEPTS/SOLUTIONS / 34

Process chain for forming and consolidating fiber-reinforced thermoplastics and metallic sheets in a two-stage isothermal tool

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Thanks to their good mechanical properties and low structural weight, multi-material structures are a promising approach in the automotive industry to lightweight design, body construction and functionalization. Especially metal and plastic are mainly combined to achieve improved properties of the final component compared to mono-material structures.
This paper describes the development of a manufacturing cell for the joint forming and heat-assisted press joining of steels and continuous fiber-reinforced thermoplastics in the form of unidirectional carbon-fiber tapes. The structure of our so-called sandwich components is as follows: Steel, PA6-slide, carbon-fiber tapes, PA6-slide, steel. Such components are usually manufactured in variothermal tools. These tools are characterised by the fact that they have to be heated when the material has been inserted and then the material can be formed. Afterwards, the formed compound must solidify again in the tool, which is done by cooling down the entire tool. Process times of five minutes are not uncommon. In order to achieve shorter cycle times and to ensure economical production, a manufacturing cell, supplemented with automated handling by means of two robots and an isothermal, two-part tool concept was developed and tested.
By the first robot, the individual components are stacked to a semi-finished product and thermally joined at specific points so that they are secured against slipping. The second robot is responsible for transferring the semi-finished products into the heating/forming tool. Simultaneously, while the sandwiches are undergoing the heating and forming process, the first robot stacks a new batch of semi-finished products. Every 30 seconds, the press opens and a finished part is removed, a heated part is placed from the heating die into the forming die, and a new stacked sandwich composite is transferred into the heating die. This means that both the heating tool and the forming tool are in operation during each press stroke. The temperature of the forming tool is set in such a way that the forming can be completed before the plastic solidifies and the composite component can be removed by the second robot immediately after the forming process without cooling the forming tool. A process window for joining was developed by testing and analyzing different holding times in the mold, pressures and temperatures.
The composite components produced were tested with regard to their dimensional accuracy, the mechanical performance and the adhesion between the joining partners. The feasibility of the production was demonstrated. All composite components had a higher specific load capacity than a pure steel component. Cycle times of well under 60 seconds were achieved. An enormous reduction in process time compared to variothermal tool concepts could be achieved with the new manufacturing cell.

TOOLS AND DIES / 35

Optimization of wear performance of Vanadis 6 steel through appropriate strategy of cryogenic treatment and tempering

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In this work, Vanadis 6 cold work tool steel was vacuum austenitized, room temperature quenched, differently cryogenically treated (-75, -140 and -196 ℃ for different durations) and double tempered, in the range 170 – 530 ℃. Two kinds of wear performance assessment were used: pin-on-disc and reciprocating sliding wear tests, by using a ball-on-flat contact configuration. Pin-on-disc testing was realized by using three different counterparts (alumina, 100Cr6 ball bearing steel and CuSn bronze) while only alumina was utilized for reciprocating sliding wear tests. Both testing types were carried out at wide ranges of sliding velocities, loads and sliding distances. The obtained results show that cryogenic treatments combined with low temperature tempering improves abrasive- and adhesive wear performance of the steel as well as its galling resistance. The best tribological properties were obtained when low-temperature tempering was combined with cryogenic treatment at -140 ℃, due to the greatest carbides count and other microstructural alteration generated by this kind of treatment. The improvement in wear performance is accompanied with slight but undisputable increase in corrosion resistance of the steel, at almost no affected toughness as compared with the state after conventional heat treatment. In conclusion, the obtained results imply an opportunity to simultaneously improve wear performance, corrosion resistance and toughness of the examined steel, by choosing a proper combination of cryogenic treatment and tempering.

TESTING, TESTBEDS / 36

Optimised parametrisation of the MMC failure model using acoustic emission and FE analysis

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In order to save resources in component production, the use of finite element (FE) simulations is state of the art during the design of the process. Thus, expensive tool modifications can be prevented and laborious experimental tests can be reduced. For a high accuracy of a FE simulation, realistic material data is required to model the material behaviour. Unlike the flow behaviour, the characterisation and modelling of the failure behaviour has not yet been standardised. Conventionally, tensile tests with different specimen geometries are performed and monitored with an optical measurement system. The failure of the material is determined contact-free on the specimen surface. However, for many materials the initiation of material failure is assumed already to initiate of the specimen prior to a macroscopic visible fracture on the specimen surface. To take this effect into account, various tests with butterfly specimen were performed for an HCT980X steel and monitored with an optical as well as acoustical measurement system. The displacement at failure of the HCT980X was evaluated conventionally for fracture on the specimen surface based on pictures of the optical measurement system. Further, the displacement at material failure was evaluated unconventionally for fracture initiation inside the specimen by a sharp increase of the amplitude based on the signals of the acoustical measurement system. FE models of the butterfly tests were created with failure displacements of both evaluation methods as boundary conditions. Using the numerically determined stress state and plastic strain from the butterfly tests, the Modified Mohr-Coulomb (MMC) failure model was parametrised for both evaluation methods and compared. The two methods lead to a significant difference in the course and slope of the two MMC failure models. The accuracy of the two models will be evaluated based on forming simulations using both failure models.

Speaker Country:

TOOLS AND DIES / 37

Pressure distributions in deep drawing with a passive cardanic blank holder

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Deep drawing processes are greatly influenced by the blank holder forces, as well as their local distribution. In current deep drawing tools, this pressure distribution is dominated by the compliance of the specific machine the tool is mounted on. Therefore, each tool must be manually polished to enable the desired distribution of the blank holder pressure. This regularly causes problems when transferring tools from one machine to another, for example from a try-out press to a regular press line. As both machines have unique compliances, the pressure distribution on the flange of the drawn part changes. Additional manual spot grinding is needed to achieve the desired pressure distribution on the flange.
To counteract this problem, the use of a passive cardanic blank holder is proposed in this paper. The cardanic blank holder can freely tilt around two axes, which leads to an auto-levelling effect of the blank holder on the sheet, resulting in a more uniform blank holder pressure. This effect is demonstrated experimentally using pressure sensitive film on the same tool with two different blank holders, one equipped with a conventional blank holder, the other with a cardanic blank holder.
To demonstrate transferability, the experiments are repeated on multiple single acting presses. The contribution will present and discuss the resulting pressure distributions.

Speaker Country:

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 38

Investigation on evolution of microstructure and mechanical properties of heat-treatable aluminum alloy during hot sheet metal forming process

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Modern hot sheet metal forming processes offer the opportunity, especially in the automotive sector, to meet current demands for ultra-lightweight design. Due to the increased formability at the high process temperatures, high-strength aluminium alloys are increasingly coming into the focus of the industry. However, the complex thermo-mechanical interactions within these processes can lead to undesirable microstructural changes that could have a negative impact on the final mechanical properties. The purpose of this work is therefore to investigate the microstructural evolution of age-hardenable aluminium alloys in the course of a modern gas-based sheet metal forming process and to quantify its influence on the resulting mechanical properties. For this purpose, various components were first formed at different process temperatures at laboratory scale and the areas of microstructural interest were identified. Metallographic examinations were performed to visualize the influence of process temperature and deformation on the microstructure. In the next step, artificial aging of the components was performed to increase the mechanical properties. Physical process-route simulations via tensile tests with suitable process parameters showed that the deformation has no significant influence on the final mechanical properties of the material.

FORMABILITY / 39

Characterization and modeling of edge fracture of the first and third generation high-strength steels: DP1000 and Q&P1000

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In this study, the hole expansion tests are conducted for the first and third generation high-strength steels (dual-phase steel and quenching & partitioning steel) to investigate the edge fracture behavior. Two edge conditions based on separated manufacturing techniques (waterjet/wire cutting and punching) are prepared and then followed by hole expansion tests to characterize the edge fracture. On the modeling side, we illustrate the prediction of edge fracture by two different models, i) the istropic plasticity and fracture model and ii) the anisotropic plasticity and partially anisotropic fracture model. While Mises plasticity is used for isotropic yielding and hardening, the envoling non-associated Hill48 model [1] is employed to describe the plastic anisotropy and its evolution in terms of hardneing and r-values for both materials. The hybrid damage mechanics model is employed to describe the damage and fracture behaivor. Resulting from the formulation of the plasticity model, the damage/fracture model works either purely isotopic or partial anisotropic [2]. The parameters in the model are calibrated in an inverse way by comparing with the experimental results based on tensile tests of several designed geometries to trigger fracture under stress states from simple shear to plane-strain tension. Finite element model for hole blanking is built to simulate the sheared edge of the punched hole, while smooth edge condition is assumed for the machined hole, followed by the simulation on the hole expansion. The numerical results are compared between two materials, two edge conditions and two model formulations. It is concluded that the anistropy induced through thickness localization plays a dominating role on accurately prediction of the edge crack initiation and propagation.
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SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 40

On accuracy improvement of springback prediction for aluminum stampings

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Springback analysis of an industry-type “shotgun” part had been accomplished for benchmarking aluminum stampings. The previous analysis demonstrated that for aluminum stampings, an accurate springback prediction can be obtained using Yoshida-Uemori model (Y-U model) considering material kinematic hardening behavior. However, that study was conducted using the Hill-48 and Barlat-89 yield criteria which parameters can only be calibrated using either material yield strength or material anisotropic values. The Barlat 2000 yield criterion overcomes the disadvantages of the Hill-48 and Barlat-89 models, taking into considerations of both material strain hardening and anisotropic behavior. In the current investigation, the springback phenomenon of the stamped part from the

shotgun die tryout was further analyzed using the Barlat 2000 yield criterion coupled with the Y-U model. The Barlat 2000 model was calibrated with data from the uniaxial tensile and hydraulic bulge tests. The Y-U model parameters were determined with data from the tension-compression and compression-tension tests under one-cycle loading and three-cycle loading paths. The shotgun benchmark case was simulated using FEA software LS-DYNA®. By comparing the predicted springback results with the tryout measurements, the simulation accuracy resulted from using the more advanced material models was evaluated. The influence of Young's modulus and the m-value in the Barlat 2000 model were also analyzed. Based on the current benchmark study, the best practice to achieve accurate springback prediction of aluminum stampings has been summarized for industrial applications.

Speaker Country:

FOSSIL-FREE STEEL, SUSTAINABLE MATERIALS, AND MATERIAL FORMING / 41

Research on toolpath optimization of robot-assisted flexible flanging

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Robot-assisted flexible flanging (RAFF), a cost-effective and promising forming technology for producing large-size open-edge flanging parts in multi-variety and small batches, is expected to be widely used in aerospace, automotive and other technological industries. Depending on whether the flanging angle of the forming roller is adjusted, the RAFF process of every pass can be summarized as two stages: The first stage in which an industrial robot drives the forming roller to rotate to the target flanging angle is defined as the pre-flanging stage, and then in the next stage called flanging stage, the forming roller moves to complete the flanging process of the whole blank sheet along the predetermined toolpath while the flanging angle of the forming roller remains constant. The toolpath of a certain pass is determined by the rotation velocity (to adjust the flanging angle), the revolution velocity (to complete the flanging process of the whole blank sheet) and the matching relationship between two velocities in the pre-flanging stage (synchronously or asynchronously). In this paper, the process principle of RAFF technology is illustrated by the example of shrink flanging firstly, then four different toolpaths are proposed to investigate the effect of the toolpath on the quality of the target 5A06 aluminum alloy flanging part with the forming angle of 60°. The revolution velocity of the forming roller is set to 1°/s by default as invariant in all conditions and the rotation velocity is set as 1°/s, 1.33°/s, 2°/s and 4°/s, respectively. Moreover, the matching relationship between the rotation velocity and the revolution velocity in the pre-flanging stage is also considered. Compared with the asynchronous motion of rotation and revolution of the forming roller, the maximum height of edge waves is decreased from 2.1 mm to 0.19 mm when the forming roller is set to rotate and revolve synchronously. Meanwhile, the maximum stress gradually increases from 575.4 MPa to 621.6 MPa when the rotation velocity decreases from 4°/s to 1°/s.

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 42

Evaluation of anisotropic fracture in AA1050-O sheet using uncoupled ductile fracture models with Hill48 plasticity

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Abstract: Uncoupled ductile fracture models have gained popularity for accurate prediction of fracture in ductile metallic sheets due to their ease of implementation. Accurate description of anisotropic fracture behavior is an active research field for sheet metal forming. In the present study, three isotropic ductile fracture models, i.e., modified Mohr-Coulomb, Hosford-Coulomb and DF2016 model are evaluated for an O-tempered aluminum alloy (AA1050-O) sheet. The plastic anisotropy is modeled with a non-associated Hill48 plasticity model. In order to verify the models, experiments are conducted for a 1.2 mm thick AA1050-O sheet under various loading conditions, such as uniaxial tension, in-plane shear, and plane strain tension at room temperature. For evaluating the anisotropic ductile fracture, tensile tests are carried out in 15° intervals to the rolling direction using digital image correlation technique. The experimental results show that loading histories of low to mid-range stress triaxialities show larger anisotropy in fractured displacements, as shown by in-plane shear and uniaxial tension tests, than high range stress triaxialities as shown by notch tests. The predicted fracture limit strains by the three uncoupled fracture models are compared with experimental results to evaluate the accuracy of these models.
Keywords: Ductile fracture, Stress triaxiality, Lode angle, Uncoupled damage model, anisotropy

FOSSIL-FREE STEEL, SUSTAINABLE MATERIALS, AND MATERIAL FORMING / 43

Partial resistance tempering of hot-stamped components for subsequent bending

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The manganese-boron alloy 22MnB5 is particularly used for structural and safety-relevant parts in the automotive industry. Parts made from this alloy are usually produced using the hot stamping process. In this process, the sheet is heated to over 950 ℃ using an industrial roller hearth furnace. The heated sheet is then simultaneously formed and quenched in a cooled tool with a temperature gradient of more than 27 K/s. This leads to the formation of a martensitic microstructure with a hardness value of over 450 HV10 and an elongation at break of less than 6%. The small strain potential of such components make them difficult to form after they are press-hardened. Due to high temperature gradients of resistance heating a sheet can get a local heat-treatment without a large temperature transition zone. This can be used to locally soften already press-hardened components for subsequent operations such as bending. Within the scope of this paper, resistance heating with direct current is used to soften a press-hardened 22MnB5+AlSi sheet stripe of 3 mm width. The sheet could consequently be bent over an angle of 90° without cracking the substrate.

Speaker Country:

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 44

Microstructure design for improving edge crack sensitivity of a dual phase steel

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Edge crack sensitivity is one of the critical features of multiphase steels which could limit the application fields of these promising materials which in general offer a significant lightweight engineering potential. Therefore, steel producers have got a vital interest in understanding how the microstructure influences on the edge crack sensitivity. With modern scale-bridging simulation approaches at hand, the question has been raised whether it becomes possible to deliver the desired quantitative relationship between microstructural configuration and edge crack sensitivity. Our study tries to give a first answer to this question. In detail, the numerical simulation framework relies on virtual experiments which were conducted on statistically representative volume elements (RVE) of the material´s microstructure. The applied boundary conditions were extracted from macroscopic numerical simulations of shear-cutting and subsequent forming processes, which were simulated with a strain based, state of stress dependent ductile damage mechanics model. Due to the fact that the in-house code for RVE generation applies statistical distribution functions, systematic parametric studies could be performed in which microstructural features including phase fraction, grain size, grain shape, and texture for each phase of the steel were varied. This scale-bridging strategy is used to design tailored microstructures with desired properties.

DIGITAL TRANSFORMATION, DIGITALIZATION, SMART PLANTS, SMART PRESSHOPS / 45

On-line quality control and tool wear evaluation in trimming process by data analytics technics

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Sheet metal is an extremely common form of use in broad engineering sectors and represents the main consumption of steel and aluminum in Europe. All production processes where sheet metal is used require cutting operations. Therefore, it is an extremely relevant procedure, common and of great economic importance in material-intensive sectors such as automotive, construction and engineering.
In a competitive environment where the demand for quality increases continuously and using harder to process high-performance materials, online monitoring and quality control become an attractive prospective. In this regard, application of data analytics techniques offers a promising toolset for fast and efficient analysis.
This work presents a pilot demonstration of an instrumented sheet metal cutting line that integrates online quality control and predictive maintenance concepts, namely detection of wear in tools as well as problems arising from the raw material and process.
Automated sequential cutting was performed using a straight trimming die mounted on a hydraulic press to cut DP1000 steel strip. Three piezoelectric force sensors were located in the trimming tool, collecting cycle data. Tests performed included studying the effect of blunting on the M2 (1.3343) tool, as well as the influence of correct lubrication.
The resulting data were analyzed through the extraction of several parameters from each cycle to correlate die wear-induced force response evolutions with the shear-induced deformation in DP1000 steel sheets. Extracted parameters were the maximum and minimum force of each cycle and the impulse (integrated force over time) was computed and segmented by plastic deformation and crack contributions. Our analysis show that advanced algorithms can be used to analyze sensor data on an automated installation, revealing OK/NOK conditions and anomalous events. Average trimming impulse (integrated force over time) increased due to die edge blunting by 20 %. On the other hand,

10% to 20% force decrease was measured with the lubricant applied on the cutting tool. The identification of these phenomena in the data will allow future developments of data-driven artificial intelligence models for on-line identification of tool wear in the trimming tool.

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 46

Numerical simulation of warm deep drawing of AA5182 alloy considering the effect of process variables on friction

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Warm forming is widely used to enhance formability of aluminum alloy sheets in order to manufacture components with complex shapes. Warm forming results in change of frictional characteristics at the tool-blank interface during forming. Higher friction leads to poor formability, non-uniform strain distribution, higher forming load, and poor surface finish of the component. So it is important to investigate the effect of process variables on friction at the interface in warm forming of Al alloy sheets. In this work, the tribological behavior of an Al-Mg-Mn alloy (AA5182) has been studied by performing strip drawing experiments in the warm forming temperature range (100-250°C) in lubricated condition. Experiments were conducted to investigate the effect of temperature, normal load, and drawing speed on the coefficient of friction. A significant impact on the friction coefficient is observed by the change in boundary conditions because of variation in process variables with temperature being the most influential. The results have been compared with frictional characteristics in strip drawing at room temperature. The results obtained from the strip drawing experiments have been incorporated in numerical simulations of cylindrical cup deep drawing to account for the effect of process variables on friction. The predicted drawability, thinning and load-displacement curves have been validated with deep drawing experiments at ambient as well as elevated temperatures. The results have been found to be more accurate when the effect of process variables on friction coefficient is incorporated when compared with the predictions by using an assumed coefficient of friction at a given temperature.

FORMABILITY / 47

Strain evolution during hole expansion testing of 800 MPa tensile strength hot-rolled steels

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One limitation of the standardized ISO 16630 hole expansion test is that it provides only one result: limiting hole expansion ratio (HER). In practice, steels with similar HER-values can have different cut edge forming behavior due to possible differences in strain localization tendencies. Digital image correlation (DIC) strain measurement during formability testing allows more in-detail analysis of strain-state near the cut edge. In this paper, strain evolution during hole expansion testing was investigated for three 800 MPa tensile strength grade hot-rolled strip steels. The steels were selected

to have differences in microstructures and anisotropies of mechanical properties. Two different hole expansion test methods with DIC strain measurement were utilized to investigate different edge loading scenarios: in-plane stretching with a flat-top punch and out-of-plane stretching with a hemispherical punch. Test holes were prepared according to ISO 16630 standard. In order to examine strain evolution and localization during testing, strains were measured with circle-shape sections around the hole in various distances from the cut edge. Edge fracture directions were identified and their possible connection to tensile test results, including r-values, was evaluated. Results show considerable differences in the cut edge forming behavior between the investigated materials.

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 48

Numerical analysis of the load paths and the resulting damage evolution during the deep drawing of dual-phase steel

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Within the deep drawing process chain, damage develops and evolves – starting with foreign particles from the slag as well as non-metallic inclusions leading to voids, which develop, accumulate and ultimately lead to failure. This damage accumulation and evolution along the process chain decisively influences the performance of components. Accordingly, the influence on the damage accumulation and evolution offers a lever to increase the performance of components. The final damage state in the component has been shown to be dependent on the prevailing load path by means of the stress and strain states along the process route. The investigation of the stress and strain states requires numerical modelling. From the models, the load path can then be extracted and a correlation can be obtained with the damage that results. The present work investigates the load paths during deep drawing of u-shaped profiles as a function of process set-up and process parameters of dual-phase steel DP800. The resulting load paths are extracted, analyzed and correlated with the numerically predicted damage.

TESTING, TESTBEDS / 49

Fracture toughness to assess the effect of trimming on the fatigue behaviour of high-strength steels for chassis parts

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High-strength steels are widely used in the body in white of vehicles offering a good balance between crashworthiness and lightweight design. The increased requirements of heavier electric vehicles in terms of fatigue resistance and crashworthiness highlighted that chassis parts have remarkable lightweighting potential. However, applying these grades in chassis parts is not straightforward, as the forming processes like trimming may introduce surface defects that compromise the fatigue

resistance of the component. This work aims to present a material selection strategy for the applicability of high-strength steels in chassis parts of electrical vehicles. The proposed approach allows the evaluation of the key parameters of the chassis parts in a simple way. The crash performance is evaluated through fracture toughness using the essential work of fracture (EWF) methodology. The method is applied to thin, high-strength steel employing double-edge notched tensile specimens (DENT). On the other hand, fatigue performance is investigated in terms of fatigue resistance for notched and unnotched specimens. The results for different complex-phase and dual-phase steels show a good agreement between the EWF and the fatigue notch factor. The method could help apply high-strength steel to chassis parts, as designers will have a tool to focus the expensive fatigue tests on the best material candidates.

LIGHTWEIGHT STRUCTURES / 50

Characterization of the mechanical properties of selectively embossed sheet metal materials under multi-axial loads

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The application of embossed structures close to the sheet surface allows for work hardening to be introduced into sheet metal materials, leading to an improvement in their mechanical properties. So far, this was demonstrated in previous research work via tensile tests with differently embossed dual-phase steel specimens. Since tensile tests only reproduce uniaxial loading of the sheet metal material, no conclusions can yet be drawn about the property modification that can be achieved by near-surface embossing concerning real-life, multi-axial loading scenarios such as driving a car. To get a deeper knowledge about the loading behaviour of embossed components, it is therefore important to consider such multi-axial load cases. In the investigations reported in this paper, such a multi-axial load case was realized by testing embossed specimens of DP500, DP600 and DP800 using a bending device. The tests showed an overall improvement in the yield strength and a simultaneous decrease in the elongation at break on the investigated materials. Further, the tests indicated that lower-strength materials get more influenced by embossing than higher-strength materials. By simulating the process of embossing the bending specimens and a subsequent three-point bending test, an even deeper understanding of the material property modification could be generated. Foremost, the stress and strain of the embossed and bent specimens can be evaluated during the embossing and bending process.

Speaker Country:

SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 51

Experimental investigation of the effect of W-temper forming process parameters on springback

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High-strength aluminum alloys have drawn a lot of attention because of the expanding demand for lightweight vehicle design in the automotive sector. Due to poor formability at room temperature

warm and hot forming have been advised. However, warm and hot forming methods need more steps in the production process and an advanced tooling system. In contrast, since ordinary tools can be used, forming sheets at room temperature in the W-temper condition is advantageous. However, a significant problem that must be resolved during the use of this technique is the springback of supersaturated sheets and their thinning. In this study, High strength aluminum alloy was solution heat treated, and a U-shaped bending test was carried out at different time periods between W-temper heat treatment and forming operation. As a result, it is noted that the springback is highly dependent on the time between W-temper heat treatment and forming operation, and the change of shape increases as increasing the time period. The change of shape after forming was also evaluated using numerical simulation aiming to validate the experimental result. To determine the material parameters of the kinematic hardening model for numerical simulation, uniaxial tension-unload tests were performed under different aging conditions.

FORMABILITY / 52

Accuracy of stretch flange formability prediction by considering strain gradient for actual car body parts

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The effect of strain gradient on the stretch flange deformation limit of steel sheets was investigated by hole expansion test under some forming conditions and by FEM. Hole expansion ratio was changed by changing initial hole diameter and punch shapes. It was clarified that limit deformation strain increases as it does not depend on initial hole diameter or punch shape, and thus strain gradient increases. The limit deformation thickness strain of the stretch flange portion could be changed by changing strain gradient. These results suggest that the formability of stretch flange deformation area should be determined from not only the maximum principle strain but also the strain gradient. Then, the accuracy of stretch flange formability prediction by considering the strain gradient for actual car body parts in mass production were investigated. The maximum principle strain and the strain gradient of the parts were calculated by the FEM and measured by the press parts. These results suggest that the formability of stretch flange deformation area for actual car body parts could not be predicted by the maximum principle strain or the thickness reduction. The accuracy of stretch flange formability prediction by considering strain gradient for actual car body parts could be verified by the investigations.

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRING-BACK COMPENSATION, AND GEOMETRY ASSURANCE) / 53

Measurement and prediction methods for forming limit strain of stretch bending deformation in sheet metal forming

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In this study, a new test method using protruding punch was proposed, that can separate bending and stretch deformations. In this test, the blank contact with the top and shoulder of punch, and the bending angle can be constant. After the bending angle becomes constant, stretch deformation can be applied while the bending deformation remains constant. In addition, this test method can control the inflow of materials by controlling the BHF, and it is possible to evaluate cracks during tensile bending deformation even for materials with low forming limits.
In this test, the obtained forming limit strain was higher than that of FLC during uniform deformation in the thickness direction. It is suggested that this is because the strain gradient in the thickness direction delayed the necking occurrence timing. There is a linear relationship between the strain gradient in the thickness direction and the maximum principal strain on the plate surface, which can be applied to the prediction of tensile bending cracks in FEM analysis.

FORMABILITY / 54

Forming characteristics of Al-Li alloy half-tube part based on impact hydroforming

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Aluminum lithium alloy with many excellent properties such as low density, high elastic modulus, high specific strength has been considered as the most ideal structural material for aerospace. However, the application of Al-Li alloys is always limited in complex structural components, due to its inferior plasticity at room temperature and easy cracking during cold forming. As a novel forming technology featured with high strain rate, impact hydroforming (IHF) has the characteristics of fluid flexibility and dynamic impact wave loading. To explore the possibility of improving the formability of 2195 Al-Li alloy at room temperature, half-tube part with complex structural profile and deep cavity was formed by IHF equipment. Based on the finite element simulation, the blank dimensions of Al-Li sheet and related part forming process were designed and optimized. A two-step process was adopted for the half-tube part to meet objective requirements. With characterizing the part depth and thickness, it is found that the forming depth reaches the target height value, and the maximum thinning rate is less than 25%. The formed part has high dimensional accuracy and is completely attached to the die cavity. The elongation of the bottom area is higher than 5%, which meets the requirements of alloy for aerospace structures. It also has good surface quality without wrinkles and cracks. It indicates that the high strain rate IHF technology can effectively improve the formability of Al-Li alloy at room temperature, and has a wide application prospect.

LIGHTWEIGHT STRUCTURES / 55

Micro incremental forming of thin SS304 foils and its microstructural study

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Micro-forming of thin foils is challenging due to the size effect, friction effect, and tool design. The conventional macro-forming techniques cannot be directly applied to the thin foils. The incremental forming process (ISF) can be used for thin foils since it possesses higher formability compared to the conventional process. Hence, μ-ISF experiments were conducted on thin foils of SS304 stainless steel having 50, 100, and 200 μm thickness. As-received foils were further annealed at 950℃ with a holding time of 20 mins to achieve strain-free microstructure. The Taguchi L18 orthogonal was applied to optimize the initial processing parameters for, μ-ISF experiments. Using the initial optimized parameters μ-ISF experiments were performed for all the thickness sheets up to the maximum wall angle. It was observed that the higher tool diameter and the lower step depth give the minimum roughness value in the deformed sheet. The tearing mode of failure was observed due to the formation of strain-induced martensite in the deformed sheet. The microstructure and bulk texture analysis relate the orientation and twin fraction with the deformation behavior. From the texture evolution, it was observed that the brass {110} <112>, Cube {100} <001>, and goss {110} <001> texture component has a greater influence on the formability of SS304 stainless steel thin foils.
Keywords: Stainless steel, μ-ISF, SPIF, Martensite

Speaker Country:

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 56

Research on the evolving yielding behavior and micro-mechanism in biaxial deformation of DP1180 sheet based on crystal plasticity finite element model

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Dual-phase steels (DP steels) consist of ferrite and hard martensitic phase. As they combine high strength and good formability at low production costs, they are widely used for automotive applications. Compared with the DP steels with lower strength, the DP1180 steel is more special for the volume fraction of martensite is higher than that of ferrite. In this paper, the evolving plastic yielding behaviours and insight into their microscale mechanisms of DP1180 were studied by biaxial tension experiments and crystal plasticity finite element method. The representative volume element (RVE) model of DP1180 taking the crystal structure, texture and dual phase fraction into consideration is established and the relevant parameters of crystal plasticity are reverse calibrated by the uniaxial tensile test stress strain curve. The simulated biaxial tension tests were conducted by the established RVE model to investigate the yielding micro-mechanisms of DP1180 steel, and the obtained yield loci matches well with the test results. The simulation results show that the texture has a significant effect on the contours of the yield loci. The soft ferrite grains weaken the kinetic constraints to the polycrystalline matrix and further free the rotation and plastic deformation of the neighboring grains. This study thus provides a comprehensive understanding of the effect of the microstructure (crystal structure, texture and dual phase fraction) on the yielding behavior of DP1180 steel as well as a method of virtual experiment to get the yield loci of metallic materials.

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 57

Patchwork blank design mafactured by friction stir spot welding using crystal plasticity finite element method

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The objective of this study is to design patchwork blank manufactured by friction stir spot welding(FSSW) using crystal plasticity finite element method (CPFEM). During FSSW, frictional heat and plastic flow cause local changes in microstructure and mechanical properties between joints. Therefore, patchwork blanks are manufactured by predicting the strengthening contribution of local microstructural evolution, including precipitate distribution, crystal morphology, grain size and dislocation, for FSSWed joints of AA6061-T6.

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 58

An artificial neural network approach on crystal plasticity for material modeling in macroscopic simulations

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Anisotropy plays a significant role in engineering, especially in the field of sheet metal forming. This particular characteristic stems mainly from the crystallographic structure of the metals and the influence of the rolling process, inducing preferred orientations of the grains. In this context, the crystal plasticity theory plays an important role as it accounts for the anisotropic nature of the elastic tensor and the orientation dependencies of the crystallographic deformation mechanisms. Despite the advantages and capabilities, the integration of the crystal plasticity theory in macro simulations is hindered by high computational costs. A novel approach aims to rectify this problem, through the application of machine learning. Therefore this work investigates the machine learning of crystal plasticity simulations, whereby the DAMASK simulation kit package is used both as a benchmark for quality and costs as well as for providing a data basis for the training and testing of the neural networks. A phenomenological material model for an AA5083 aluminium alloy provides the training data for a neural network study, testing different input parameters as well as network setups.

TOOLS AND DIES / 59

A machine learning model to control four-point blank holding forces for improving drawability of Al 6014 in a deep drawing process

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This paper proposes an approach for muti-defects reduction using a segmented blank holder force (S-BHF) distribution that the blank holder force (BHF) with a segmented distribution. In particular, a strategy based on finite element method, deep neural network and response surface method (FEM-DNN-RSM) techniques is constructed and optimized is used to determine the optimal S-BHF distribution and drawbead restraining force (DBRF). In this paper, the muti-defects including thinning and wrinkling are taken as the objective function. The failure of the sheet during the forming is considered as the design constraint, and the forming limit diagram (FLD) is employed to evaluate the design constraint quantitatively. It has been found from numerical results that the optimal S-BHF distribution can drastically reduce the defects in comparison with constant BHF. A cylindrical

cup provided by NUMISHEET 2011 (BM1) is used for the numerical simulation. It is found from the numerical result that the proposed approach can drastically reduce the defects mentioned at 5.6% and 7.5%.

Speaker Country:

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 60

Oxygen-free resistance heating with nitrogen and silane as an energy-efficient heating process for hot stamping

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Saving CO2 by replacing fossil fuels with renewable ones has been a goal of research for several years and has become the focus of public discussion at the latest due to the electrification of passenger cars and the much-discussed carbon footprint caused by production. Hot stamping is a process for the production of ultra-high-strength components used for passenger protection in the automotive industry. As part of the hot forming process, sheet metal blanks are heated in a gas operated roller hearth furnace to approx. 950 ℃ in 8 to 10 min and afterwards formed and quenched in a water-cooled tool. This extends the yield strength of the components up to 1500 MPa. The long heating time can be attributed to the coating of aluminum and silicon (AlSi). The coating is necessary for the hot forming process in the furnace, as it prevents scaling of the blank by forming an intermetallic phase. However, 8 to 10 minutes of heating is required to create a sufficiently stable diffusion zone between the blank and the coating Due to the long heating time and the use of gas as the energy source, the process is very energy inefficient and can only be controlled slowly. Heating is coordinated with the cycle time of the hot forming press and therefore up to 60 m long. Resistance heating provides a space-saving and energy-efficient alternative. As a result of the direct flow of current through the sheet, up to 68% of the energy can be saved compared with roller hearth furnace heating. The process is a high-speed heating process that can heat sheets up to 950 ℃ in less than 10 seconds. The heating time is not sufficient for conventional coatings that protect against scaling to bond sufficiently with the base material, which means that there is currently no viable coating for resistance rapid heating. A new approach is to suppress scale formation by reducing the oxygen during heating. The process gas nitrogen displaces the oxygen in the heating chamber. Silane, on the other hand, reacts with the oxygen to reduce oxygen to below 10-23% by volume at the XHV(extremely high vacuum) adequate level, preventing scale from forming. At the same time, this absence of oxygen is an ideal condition for applying coatings. For this purpose, a resistance heating device was developed, which is shown in this paper, which heats sheets without scale within a very short time. A stretching device was integrated to compensate for the temperature length expansion and to test coatings for their forming capability. Two variants are currently available for coating. One coating can be applied beforehand by means of PLA coating or powder can be applied during heating by nozzles. Since electrical energy is used for heating, the coating can be heated without the need for fossil fuels.

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRING-BACK COMPENSATION, AND GEOMETRY ASSURANCE) / 61

Displacement based simulation and material calibration based on digital image correlation part I - theory

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ABSTRACT

The calibration of material data to properly describe the stress response of a specific material under various loading conditions in finite element analysis (FEA) is still a challenging task. Not only that new steel grades or aluminum alloys are investigated by the material manufacturers to enhance certain characteristics of their product such as stiffness, strength, or maximum strain to failure, but also FEA software tools add new physically or non-physically motivated material models to their libraries, allowing users to improve the predictability of their process- or structural analysis with these new materials. Since depending on the model size various element lengths are utilized, it is often necessary to repeat the calibration process several times, e.g. for 0.5 mm – 10.0 mm meshes, in order to properly capture mesh size dependent damage and failure parameters.

Experimental test campaigns for material characterization are nowadays often accompanied by measurements of the displacement field of the specimen. Quite commonly, the GOM/ARAMIS optical measurement system is used for this purpose. Prior to the test, a randomized speckle pattern is sprayed onto the specimen, allowing the underlying image processing software to create triangulated facets which are used internally to calculate strain fields. Previous publications (Ilg et. al. 2019) have investigated how these locally varying strain fields can be used to improve accuracy of the parameter identification process comparing measured and simulated stress-strain responses during the optimization. Since a larger area of the specimen is used as optimization target instead of only comparing to the force response, this method is called Full-Field Calibration (FFC). Another method utilizing measured strain fields based on the Principal of Virtual Work is the so-called Virtual Fields Method (VFM) proposed by Grédiac et. al. 2006. Within a selected area of interest, virtual fields are created, allowing to establish scalar equations which together with a selected constitutive model help to obtain the unknown material parameters. Marth et. al. 2016 proposed a piecewise modelling technique, identifying the integration path for force calculation from the last measured state prior to specimen failure. Yield stress vs. effective plastic strain curves can then be derived "piecewise" based on the deformation gradient at each experimental time step and an underlying constitutive equation.

Within this work, we investigate the possibility to combine finite element data mapping with material calibration. Therefore, we transfer the displacement field measured with the GOM/ARAMIS system onto finite element meshes with different element sizes as nodal boundary condition. This allows us to simulate the behavior of the specimen as realistic as possible for several mesh sizes while deriving material parameters through an optimization process. This contribution is split into two parts: the first dealing with the theoretical background and implementation of the image processing and finite element data mapping into the software Envyo®, the second with the parameter identification using LS-OPT®, LS-DYNA®, and a modified test specimen, which provides a broader range of various stress states than the currently used standardized tensile specimen (Ilg et. al. 2023).

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Keywords: Material Calibration; DIC; Optimization, Displacement Field Mapping

Speaker Country:

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRING-BACK COMPENSATION, AND GEOMETRY ASSURANCE) / 62

An overview of Methods for Simulating Sheet Metal Forming with Elastic Dies

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Sheet metal forming (SMF) simulations are traditionally carried out with rigid active forming surfaces. This means that the elasticity and dynamics of presses and die structures are ignored. The only geometries of the tools included in the simulations are the active forming surfaces. One reason for this simplification is the large amount of computational power that is required to solve finite element (FE) models that incorporates elastic stamping dies and presses. Another reason is the lack of die CAD models before the later stages of stamping projects. Research during the last couple of decades indicated potential large benefits when including elastic dies and presses in SMF simulations. For example, for simulating die try-out or for Digital Twins of presses and dies. Even though the need and potential benefits of elastic dies in simulations are well known it is not yet implemented on a wide scale. The main drawbacks have been lacking data on presses and dies, long simulation times, and no standardized implementation in SMF software for setting up the simulations. This paper presents an overview of existing methods for SMF simulations with elastic dies and discuss their respective benefits and drawbacks. The survey of methods shows that simulation models with elastic tools will be needed for highly detailed analyses of forming operations, and for purposes like training digital twins. Knowledge can be extracted from advanced models to create value for the tool manufacturing or stamping shops. On the other hand, simplified and robust models can be developed for non-FEA users to carry out simple one-step compensation of tool surfaces for virtual spotting purposes. Methods identified in this paper should be the topic of future research. All methods have their respective pros and cons and should be considered for different research and implementation tracks going forward.

Speaker Country:

TESTING, TESTBEDS / 63

Determination of anisotropy yield function coefficients with a displacement field of a limiting dome height test using a deep neural network model

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In this research, coefficients of anisotropy yield function Yld2004-18p were determined with a displacement field of a limiting dome height (LDH) test using a deep neural network (DNN) model. Finite element analyses of the LDH test were conducted with different sets of yield function coefficients, and the r-direction displacement fields in a cylindrical coordinate system were extracted to generate training and validation data for the DNN model. The displacement fields were extracted on a regular grid of r- and □- axes that were uniformly divided by 91. The DNN model has an input layer with 8231 neurons that take the displacement field data, seven hidden layers and an output layer with 14 neurons that give the coefficients. Al 6014 was adopted to verify the proposed model.

The coefficients of the yield function of the material were obtained with the conventional tensile tests in seven directions, and these were compared with the ones obtained from the proposed DNN model.

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRING-BACK COMPENSATION, AND GEOMETRY ASSURANCE) / 64

Three Industrial Cases of Sheet Metal Forming Simulations with Elastic Dies

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Sheet metal forming (SMF) simulations are traditionally carried out with rigid tool surfaces. This research aims to enable simulations with elastic dies for industrial-sized stamping dies. This is important for die try-out, digital twins, production control, and other topics in the current frontier of SMF research. No method in the literature is fully developed for simulations with industrial sized dies using elastic tools. A promising method is selected from the literature, after important modifications it is deemed to be fast and robust. The method consists of using explicit time integration where the die structures are meshed with a coarse solid mesh. The forming surfaces are modeled with a finer shell mesh attached to the tool mesh by contacts with offset. The selected model is used to reduce tryout time by >50%, a significant achievement. Two cases of production support are also demonstrated where the elastic and dynamic blankholder modeling is key. One of the main criteria in favor of the selected approach is the realistic modeling of blankholder and cushion systems in forming presses. There is an increase in preprocessing and simulation time compared to using rigid tools, but industrial dies can now be modeled within an hour and solved within a working day. It is also easy to update the model by replacing separate parts such as die solids or forming surfaces. One frontier in the SMF research area is digital factories monitored and controlled by smart digital systems, areas where this research can be further utilized.

Speaker Country:

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRING-BACK COMPENSATION, AND GEOMETRY ASSURANCE) / 66

Displacement based simulation and material calibration based on digital image correlation part II - application

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ABSTRACT
In finite element analysis (FEA), improving the accuracy of the prediction capability of material

cards to obtain the correct stress response of a specific material is still a major challenge in the field of forming technology. Furthermore, new aluminium alloys or steel grades are steadily released by the material manufacturers, differing in their attributes such as stiffness, strength or maximum elongation. And not only the material manufacturers, but also the FEA software tools developers are expanding their material libraries with increasingly complex constitutive models. This often requires extensive reverse engineering strategies and multiple experimental tests – primarily tensile tests – to achieve a sufficient quality of the material cards. As a result, more complex characterization strategies, time-consuming calibration processes and increased costs are inevitable.
The usage of optical measuring systems (DIC) during experimental tests is common practice in the area of material card calibration, since a lot of information of the material behaviour can be obtained, e.g. by means of grayscale correlation. But in most cases, material card calibration strategies are based only on the optimization of some of these information from the DIC, such as Lankford parameters or stress-strain curves. Previous publications have demonstrated how the data of the complete distortion field can be used via full-field calibration (FFC) for parameter identification of yield curve extrapolation approaches (Ilg et. al. 2019) or for the optimization of the yield locus (Hippke et. al. 2020). Grédiac et. al. 2006 utilizes the data from full-field measurements too and proposed the Virtual Fields Method (VFM), which identifies parameters based on the Principle of Virtual Work.
The theoretical investigation and software development presented by Liebold et. al. 2023 will be utilized within this work. Thereby, displacement driven simulations based on an optical measurement with the GOM/ARAMIS system are used for material card calibration. Therefore, the measured distortion field of a tensile test gets transformed into a LS-DYNA® input deck with the software Envyo®, allowing to locally provide the same or at least the interpolated displacements at discretized nodes in the FEA model and in the experiment. To investigate the improvements made by this approach and to show its applicability for different mesh sizes, a new tensile specimen providing a wide range of various stress states is presented. The iterative parameter identification process is performed using LS-OPT® and is applied to different material models that are implemented in the LS-DYNA® material library, including isotropic and anisotropic material models.

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Keywords: Material Calibration; DIC; Optimization.

Speaker Country:

DIGITAL TRANSFORMATION, DIGITALIZATION, SMART PLANTS, SMART PRESSHOPS / 67

Application of a neural network for predicting the cutting surface quality of punching processes based on tooling parameters

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Punching represents one of the most frequently used manufacturing processes in the sheet metal processing industry. Thereby, one of the most important quality criteria for such punching processes constitutes the geometric shape of the cutting surface. High cutting surface qualities are usually

characterized by the lowest possible edge draw in, a high clean cut, as well as a small fracture surface and a low burr height. In this respect, conventional punching processes can only produce clean cut proportions (CCP) up to 20-50% of the sheet thickness. By means of the so called “concave punch nose design” developed at the Institute for Metal Forming Technology, the geometry of conventional punches could be optimized in such a way that the clean-cut proportion along the cutting surface is significantly increased. We will show, that the quality parameters of the sheared component edges thereby show highly nonlinear relationships to the tooling and sheet metal material parameters used. In order to quantify these effects, the data from several numerical punching simulations is used to pretrain an artificial neural network. Input data for the neural network included features of the punch geometry, the size of the clearance, the sheet thickness and the material data of the semi-finished product. The output of the neural network is precise predictions of the achievable cutting surface quality parameters. Our experimentally validated findings show that the process design for novel punching processes is possible, when using a modern machine learning approach.

TOOLS AND DIES / 68

Novel tool steels for application in hot stamping

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Hot stamping is a commonly used procedure to manufacture components from high strength steels, which are used for parts of car bodies. Against the background of production efficiency and costs, there is a number of factors which determine the performance of tools used in hot stamping, e.g. cycle time in production and lifetime of the tools. Main requirement is a high wear resistance, while additional properties such as high thermal conductivity can be considered being beneficial. Many steel grades, which are currently applied in hot stamping tools (e.g. hot work tool steel 1.2367) contain high amounts of alloying elements which gives them good mechanical properties, particularly at high temperatures. However, these steels in turn suffer from a rather low thermal conductivity and only moderate wear resistance. Optimization of the balance of mechanical properties, wear resistance, and thermal conductivity can lead to a better general performance of hot working tool steels used in hot stamping applications.
In this study, a novel tool steel is characterized with special focus on properties relevant for hot stamping tools. Results are compared to those of reference hot work tool steels. Wear tests that had been conducted in the framework of this paper include laboratory setups like ASTM G65 / G75 and high-temperature strip-drawing test setups to simulate the conditions of the process closer to reality. Results show that the novel tool steel is characterized by an increased wear resistance in combination with a higher thermal conductivity compared with common hot work tool steels. Furthermore it is approved that a wide range of desired properties can be adjusted in this alloy via heat treatment. The favorable combination of properties makes the novel tool steel suitable for application in hot stamping tools.

TOOLS AND DIES / 69

Prediction strategy for forming and joining process of oval tubes

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High requirements on the CO^2 emission of cars, lead to the production of new filter systems with complex geometries. In this paper, the effect of manufacturing oval tubular components instead of circular components for the exhaust system is investigated numerically and experimentally. For this purpose, the manufacturing process is divided into the forming process and the stuffing process. In the forming process, the as-delivered tubes are radially expanded in several steps (calibration and endforming). The occurring inhomogeneous strain distributions lead to a complex springback behavior, which results in deviations between the nominal and real geometry.
These shape deviations, the manufacturing tolerances of delivered parts and the non-linear and time-dependent material behavior of the rubber-like components lead to a unique deformation behavior of the components during the last process step (stuffing).
For the numerical analysis of this process, a procedure is presented, which predicts the geometry after the forming process and after stuffing. During the validation of the model, it has been shown that the deviation of the supplied parts must be taken into account in order to predict the final geometry with sufficient accuracy using numerical simulation.

TRIBOLOGY / 70

Friction and lubrication modelling in sheet metal forming: Influence of local tool roughness on product quality and process robustness

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To improve the accuracy of forming simulations advanced friction models are increasingly used in industry. These models account for the physical properties of the sheet, tool and lubrication and describe the tribological conditions during the forming operation. One of the main influencing factors on the tribology system, and therefore the friction coefficient, is the surface roughness of the tools. Until now, it is often assumed the tool has the same surface roughness over the whole area. In reality however, the tool might have different surface conditions dependent on the type and location of the tool. That is, the blank holder might be differently polished then the punch, and sharp radii might have a finer tool roughness compared to flat areas. This paper investigates a significant number of tool measurements from different try-out and production dies from Volvo Cars, and quantifies the effect of local surface conditions on product quality and process robustness. The study is motivated by Volvo Cars where the majority of forming simulations are performed to secure die tryout, i.e. to solve as many problems as possible in forming simulations before the final design of the die and milling of the casting.

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 72

Development of a new cyclic shear test setup for characterizing thin metallic foils

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Recent developments aimed at reducing cumulative CO2 emissions in the energy sector and e-mobility are leading to an increase in the production volumes of formed components made from thin metallic foils used for alternative energy supply concepts. Thus, components such as bipolar plates in fuel cells and a variety of parts in e-motors and batteries are being manufactured in ever higher quantities and thinner material thicknesses. As a consequence, this leads to increased challenges regarding the feasibility and robustness of required production processes. FE-simulations represent a useful tool in this context to predict and to optimize the results of forming processes at an early stage of development. The prediction accuracy of such simulations thereby significantly depends on the modeling of the material behavior, which is derived from material characterization methods. However, classical approaches to material characterization usually tend to fail in case of thin metallic foils, especially when the structural stability of the specimen becomes an important factor for the validity of the characterization test. The cyclic shear test, for example, is used to determine the hardening behavior of the material to be characterized, but is unsuitable for metallic foils unless a special anti-wrinkling device is used. Current anti-wrinkling devices proposed in literature must be attached directly to the deforming area of the specimen, apply pressure to the specimen surface, and must also be transparent to allow optical measurement of the deformation. Attaching such devices to prevent the specimen from wrinkling requires extreme skills to avoid deforming of the specimen even before testing. Against this background, this paper presents a novel experimental setup, which increases the structural stability of the cyclic shear specimen and thus prevents wrinkling without the use of an additional device in the measurement area during the test procedure. Structural stability is enhanced by curving the gauge area of the specimen to drastically suppress the tendency to wrinkle. As a proof of concept FE-simulations with LS-Dyna were performed in this study to verify this novel idea and to design the experimental setup.

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Formability evaluation based on a constitutive model with stress rate direction dependency considering bifurcation modes

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Accurate prediction of fractures that occur in a material during forming not only improves quality, but also reduces the amount of material that is discarded. Formability evaluation is generally performed using ductile fracture criteria or experimental forming limit diagrams (FLDs), but these require fracture tests to be conducted beforehand. The authors have established a formability evaluation method based on the three-dimensional local bifurcation theory, which is a highly general method that does not require fracture tests. A flow rule that takes into account the dependence on the direction of the stress rate is used in this method, which can track abrupt changes in the stress field, such as localized necking. In this study, the proposed method is applied to forming analyses such as square-cup drawing and hole-expansion tests to analytically verify the location and initiation timing of local bifurcation modes that may lead to failure.

TESTING, TESTBEDS / 74

Cruciform tension-shear test for sheet metal and application to material modeling of mild steel sheet

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Stress measurement errors in the tension-shear tests using a cruciform specimen are evaluated. The tension-shear test method was proposed by Minki et al (2022). A servo-controlled biaxial tensile testing apparatus is used as the testing machine. The gauge area (GA) of the tension-shear specimen receives normal stress, σxx, and shear stress, σxy; however, the stress distribution in the GA is not uniform. Therefore, the average stress, σave, is calculated by dividing the testing force by the average cross-sectional area of the GA. The average cross-sectional area is obtained by measuring the strain distribution of the GA with DIC. On the other hand, the deformation of the cruciform specimen is analyzed by finite element analysis to calculate the stress distribution at the GA, and the stress components at the strain measurement position by DIC is determined as the true value, σt. We can evaluate the stress measurement error, as (σt-σave)/σt. Next, various linear stress paths (σx/σxy=const.) are applied to the cruciform test piece made of a cold-rolled mild steel sheet, and the stress points forming the contours of equal plastic work in the σxx-σyy-σxy stress space were investigated. Then, we identify the Yld2000-2d yield function that can approximate these stress points. Furthermore, by comparing that with the Yld2000-2d yield function identified by conventional biaxial and uniaxial tensile tests, the effect of the tension-shear test on improving the accuracy of material modeling is investigated.

TESTING, TESTBEDS / 76

A uniform method for the characterization of shear fracture strain for high-strength steel sheets under quasi-static and crash loading

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In the conflict between lightweight design and crash safety of high-strength steel components failure models for crash simulation have to be calibrated precisely. Especially the negative strain rate effect concerning the shear failure strain of high-strength steel sheets as well as the fact that ductile shear failure occurs immediately and without previous necking are safety-critical aspects. For an accurate prediction of shear failure strains in a wide strain rate range shear experiments must be performed from quasi-static up to crash-relevant strain rates of about 100 s-1. For this notched shear tensile specimens are frequently used, however, with the tendency to produce early failure in the notch region. Different investigations in the past propose optimized shear zone geometries with delayed or without notch failure. Though, the influence of the free length between the grips and the type of clamping also have a pronounced influence on the deformation and failure behavior of the widely used asymmetrical notched shear tensile specimens.
In this contribution a characterization concept for shear loading in a wide strain rate range based on asymmetrical notched shear tensile specimens is presented for high strength steel sheets of different strength, ductility and sheet thickness. The influence of the number of degrees of freedom in the clamping area and of the free length between the grips on the kinematic of the specimens and on the deformation and failure behavior in the shear zone are investigated in detail. As a result, shear deformation and shear fracture is supported by a clamping with translational degrees of freedom in horizontal direction or by an increase in the free length between the grips. As an experimental

determination of shear failure strains evaluation strategies with and without optical measurement techniques are proposed. For this reason, a uniform method for the strain rate dependent characterization of steel sheet metals under shear loading is developed and the status of standardization is presented.

FORMABILITY / 78

Effect of pre-strain on the edge formability of high strength steels for chassis applications

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Keywords: Sheet metal forming, high strength steels, Edge formability, Chassis, Pre-strain, Hole tension test

Abstract

There is a high level of uncertainty in the prediction of edge cracking during the design and manufacturing of high strength sheet metal products. Edge ductility is a complex parameter to measure since it is not an intrinsic property of the material, but it also depends on the trimming strategy/parameters that have been applied to the edge (edge preparation method, cutting/punching clearance, etc.). Furthermore, most of forming processes involve more than one operation where the material can be deformed in a first stage, then trimmed or punched and further deformed in a final forming step to obtain the desired shape. Therefore, in order to design a robust and safe forming process able to predict the risk of edge cracking, it is crucial to understand the influence of pre-strain on the residual formability of trimmed edges. This paper analyses the effect of different pre-strain levels and paths (uniaxial tension, plane strain and equibiaxial stretching) on the sheared edge ductility of a Complex Phase (CP) steel and a high strength low alloy (HSLA) steel used for automobile chassis applications. To this purpose, rectangular specimens are cut out from pre-strained samples and punched. Hole Tension Tests (HTTs) in combination with Digital Image Correlation (DIC) are carried out to determine the edge fracture strain of undeformed and pre-strained samples. The results are discussed in terms of major strains obtained from DIC and thickness strains measured by optical microscopy. The proposed methodology allows to describe the edge cracking sensitivity of high strength steel sheets as a function of the pre-deformation state and can be useful to predict the risk of edge cracking more accurately in forming simulations.

LIGHTWEIGHT STRUCTURES / 79

Manufacturing of light weight connecting rod by hot stamping process

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A Connecting rod (CR) is an essential part of the internal combustion engine. It transmits the energy generated in the combustion chamber to the crankshaft. Conventionally, the connecting rods are solid parts made of steel material forged to the required shape in several steps. This study has designed and simulated a process to manufacture hollow CRs by sheet metal forming processes. The

material used in the present analysis is a 22MnB5 hot stamping steel sheet of 3 mm thickness. A single-step hot embossing and hole flanging process has been designed to deform the part to the required shape at high temperatures to obtain low flow stress and high formability in the material. The quenching of the formed part to room temperature converts the austenitic phase to higher strength martensitic phase, leading to an increase in the strength of the material.
The designed connecting rod is for Kirloskar Oil Engine Ltd.'s four-stroke air-cooled direct injection engine. The designed CR has similar functional dimensions and strength to the existing solid connecting rod. An innovative design has been used to form a hollow part to increase the structural strength and decrease the weight of the part. The produced part has up to 30 percent lower weight than the existing-forged-solid connecting rod.

TOOLS AND DIES / 80

Optimization of the physical scaling approach through adaption of the inverted membrane stresses

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Dimensional deviations of stamped car body components caused by elastic springback still represent a significant problem for the development of the stamping tools. First, the springback causes deviations of the part in vertical direction to the part surface. Second, the surface area of the part is being changed by elastic membrane stresses resulting in a contraction of the surface but, additionally, in deviations of the first kind as well. The precise manifestation of the contraction depends both on the part stiffness and on the membrane stresses normally being heterogeneously distributed over the part surface. Usually, the resulting deformations cannot adequately be compensated by globally homogeneous scaling approaches. In order to carry out a locally correct compensation of the stamping tools, Birkert et al. have recently presented a physical scaling approach based on the inverted membrane stresses gained from the part in the closed die to compensate the active die surfaces. This approach delivered significantly better results but left potential for improvement.
It is shown in the present paper how the existing approach can further be improved by adapting the inverted membrane stresses in an appropriate way. This is done by comparing the amount of strain changes during spring-back with those of the scaling process in a first step and adjusting the compensation stresses, in a second step, in such a way that the considered strains are more or less identical.

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 82

Impact of elastic modulus evolution on springback prediction

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The Yoshida-Uemori model is a combined hardening model coupled with the elastic evolution modulus which depends on the equivalent plastic strain. This model is implemented in the most used

FEA stamping codes with occasionally some variations in the form of material cards. The material cards are requested regularly by the car manufacturers, in order to get a more accurate prediction of springback by numerical simulation, when compared to the prediction with a purely isotropic hardening mode. ArcelorMittal can provide material cards to its customers, thanks to an in-house methodology to identify the Yoshida-Uemori parameters in a very precise and robust manner.

The method used for the identification of the two material parameters governing the evolution of the elastic modulus can be further improved. The method is based on the use of experimental data coming from hysteresis loops conducted between 0.2% of plastic deformation and uniform elongation (Uel). During the unloading path of the loop, the force decreases until 5N. Several methods for defining the unloading elastic module have been tested and evaluated in this paper:
- Today, the elastic modulus is the slope deducted from the linear regression on all points of unloading path.
- The elastic modulus is the slope deducted from the linear regression on a part of unloading path.
- The elastic modulus is the chord modulus

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRING-BACK COMPENSATION, AND GEOMETRY ASSURANCE) / 83

Prediction of texture-induced plastic anisotropy in AA6014-T4 aluminium sheets utilising two different crystal plasticity constitutive models

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Virtual experiments based on crystal plasticity simulations are a common approach to predict the texture-induced plastic anisotropy of polycrystalline sheet metals. Such simulation approaches utilise a crystal plasticity constitutive model that describes the deformation behaviour of single crystals on the base of crystallographic slip. However, there are different mathematical formulations of crystal plasticity constitutive models available in the literature. In this conference paper, two crystal plasticity constitutive models that differs with respect to the flow rule (rate-depended/rate-independent) and hardening law (phenomenological/physical-based) are compared with each other. To this end, both crystal plasticity constitutive models are deployed in combination with the finite element method to simulate the plastic anisotropy of an AA6014-T4 aluminium alloys regarding uniaxial loading in 0°, 15°, 30°, 45°, 60°, 75° and 90° with respect to the rolling direction and biaxial loading. The results of the stress strain curves, normalised yield stresses and r-values demonstrate that both crystal plasticity constitutive models provide comparable results. Also, the experimental r-values are predicted with reasonable accuracy. Differences with respect to the experimental normalised yield stresses are discussed and most likely caused by precipitates.

TESTING, TESTBEDS / 84

Stretch flangeability of AHSS versus micro-hardness, grain rotation and 3D stereo microscopy fracture topography characteristics

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Stretch-flangeability investigations have been performed by means of ISO16630 conical hole expansion tests for some automotive cold rolled AHSS advanced high strength steels with different cutting clearances (5-7%, 12%, 20% and 26-27%).

The HV0.025 Vickers micro-hardness (25g load) increases between bulk material and cut edge vicinity. This bulk to edge hardness hardening decreases with increasing clearance. The width of the shear affected zone (SAZ) increases with increasing clearance and decreases with increasing strength level. No obvious correlation with hole expansion ratio (HER) values could be found.

A strong gradient in grain rotation shear angle values vs. distance from cut edge is observed on Nital etched metallographic sections normal to punched hole edge. The SAZ zone width increases with increasing thickness, clearance and material work hardening ability. HER values however do not correlate particularly well with such grain flow motion parameters.

By means of 3D stereo microscope investigations on punched hole fracture surfaces, it can however be shown that rather physical geometric notches (burr, secondary burnish, cut edge roughness in fracture zone) within punched edge profile are the driving force behind AHSS edge crack sensitivity. A “nice” shear cut edge with a straight linear edge profile in the fracture region is reached around 15% clearance and correlate quite reliably with best HER-values for any material investigated.

FOSSIL-FREE STEEL, SUSTAINABLE MATERIALS, AND MATERIAL FORMING / 85

Evaluation of hardening models coupled with shear modified Lemaitre damage model for fracture prediction in incremental sheet forming

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Incremental sheet forming (ISF) is an emerging technology for manufacturing sheet metal components with fewer tools and equipment compared to conventional sheet forming. In this process, forming is generally performed without dies and punches and a simple hemispherical shaped tool can be used for shaping the final component. Forming limit in incremental sheet forming can be defined by the maximum formable wall angle. Finite element analysis can be used for formability prediction by using a damage model. Also, to define the material flow behaviour hardening law should be incorporated into the finite element model. In this study, three different hardening laws were used with shear modified Lemaitre damage model for fracture prediction during ISF of AA1050 alloy. The effectiveness of Swift, Swift-Voce hybrid and Hockett-Sherby hardening laws were compared for fracture prediction. Further, the predicted fracture wall angles were compared with the experimental observations. The results were analyzed in terms of damage and strain evolution for the predicted fracture wall angles based on different hardening models.

ADVANCED/SMART MATERIALS, BIPOLAR PLATES, AND MULTI-MATERIAL CONCEPTS/SOLUTIONS / 86

Process parameter optimisation and wear testing of DED-produced metal matrix composite of NiCrSiBC-60% WC for tool surface cladding

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Metallic additive manufacturing processes have experienced significant growth in the past decade, with surface cladding being an important application, especially within the context of tools used in the forming and die industries. One of the possible objectives in surface claddings is the improvement of a component's hardness and wear resistance, with metal matrix composites (MMCs) allowing a balance between a material's printability and hardness. In this work, directed energy deposition process parameters regarding the manufacture of a NiCrSiBC matrix with tungsten carbide particles were optimised using orthogonal design of experiments, with the aim of minimising internal porosity and cracking, as well as maintaining dilution proportions between 10 and 30%. Pin-on-disk samples for wear testing are to be produced and tested, as a mean to evaluate the behaviour and validity of this material combination as surface coating when produced via DED.

TESTING, TESTBEDS / 87

Bendability assessment of advanced high strength steels thanks to artificial neural networks

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Thanks to their very important strength in addition to their considerable formability and ductility, the newly developed Advanced High-Strength Steel (AHSS) allow carmakers to save mass on the vehicles they produce. However, before industrial implementation by OEMs, any grade has to be approved. The bending test defined in VDA238-100 standard is a key indicator of the material ductility and is increasingly requested in the scope of their homologation. The test consists in bending a square sample of sheet material with a knife. The sample is supported by two rolls. The aim of this test is to determine the maximum angle reachable by the sample before it breaks. We can also derive the maximum strain reachable by the material before fracture initiation.
Mainly 2 different angles are defined: the angle after springback, that can be measured manually and the angle at maximum load, which is to be considered in the VDA 238-100. The standard gives instructions on the determination of the bending angle. Nevertheless, the approach is purely geometric and only relies on the parameters of the test. No influence of the tested material is taken into account. This approach can be improved because for AHSS that are very ductile and have a bending angle over 80°, the proposed formula can provide unphysical results.
For this reason, the innovative proposed approach is to calculate the bending angle at maximal force and to determine the fracture strain thanks to Artificial Neural Networks, one of the most promising tools for resolution of engineering problems. This new approach considers a large panel of materials tested experimentally or numerically and significantly improves the prediction.

Speaker Country:

TRIBOLOGY / 88

Physics-based modelling of interfacial heat transfer coefficient in the hot stamping of Al-Si coated 22MnB5 steel

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Knowledge of the interfacial heat transfer coefficient (HTC) between a blank and water-cooled tool is critical in the design of automotive parts made of press hardenable steels [1]. A physics-based model was developed to predict and explain the transient behavior of the HTC in the hot stamping of Al-Si coated 22MnB5 steel. The surface of the austenitized blank was modelled from its measured microscopic topography to capture imperfect thermal contact between the blank and die. The heat diffusion equation was solved to predict the transient, three-dimensional temperature field within the blank and die during quenching. The progressive improvement of thermal contact due to the gradual press tonnage ramp up and transformation of austenite to martensite was captured by a nonlinear mechanical submodel, which assumes the surface elements of the blank deform uniaxially. The HTC history, which was inferred from the model-predicted temperature field, resembles experimental findings. The present model suggests that the evolving thermal conductivity of 22MnB5 may not have a significant impact on the HTC due to the shielding behavior of the resolidified Al-Fe-Si coating layer. The model also explains the increase in HTC in response to shorter press force ramp up durations, thicker blanks, and higher initial blank and die temperatures.

[1] H. Karbasian and A. E. Tekkaya, "A review on hot stamping," Journal of Materials Processing Technology, vol. 210, pp. 2103-2118, 2010.

FORMABILITY / 89

Forming of a cylindrical cup in 7075-T6 under warm temperature conditions

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The use of aluminium alloys with high mechanical properties is very interesting to reduce the weight of parts, especially in the automotive field. However, a formability problem prevents the use of these alloy at room temperature (RT), especially for complex shapes where part failure occurs before complete drawing. The use of a warm forming process, which consists of heating the part between 150℃ and 250℃ for aluminium alloys, allows to increase formability and therefore to perform complex shapes. In this study, forming of a cylindrical cup in 7075-T6 for temperatures ranging from RT to 200℃ are simulated in Abaqus. Forming is performed in two steps by two reductions of the blank diameter. Numerical simulations show that the stresses and plastic strains in the cylindrical cup are higher than the material can withstand at 20℃, while at 200℃ the stresses and plastic strains are acceptable, allowing the cup to be drawn in two stages.

FORMABILITY / 90

Determination of edge fracture limit strain for AHSS in the ISO-16630 hole expansion test

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For decades, the ISO-16630 Hole Expansion Test (HET) has been the industry standard for expressing the edge formability of sheet metals through the Hole Expansion Ratio (HER). However, in recent years, this test has been criticized for its high scatter in results for repeated experiments. This scatter has been suspected to be caused by the operator-reliant post-processing of the test, or variations in the cutting conditions for the different test specimens. A previous study by Barlo et al [1] investigated the boundary conditions of the test by introducing draw beads to the experimental setup as well as use images captured by a 3D DIC system to evaluate the hole expansion ratio, thereby reducing the impact of the operator-reliant post-processing.

This study will build on top of the conclusions of [1] by investigating the hypothesis that the scatter is caused by the stochastic behavior of fracture and move the point of the evaluation from a through-thickness crack to the onset of surface fracture to get a more realistic evaluation suited for industrial use. As the experimental setup used by [1] deployed a 3D DIC system, FEM models can be calibrated against the experimental results, and a fracture limit strain value can be determined from the calibrated models.

References

[1] Barlo, A et al (2022). "A Study of the Boundary Conditions in the ISO-16630 Hole Expansion Test". IOP Conf. Ser.: Mater. Sci. Eng. 1238 pp. 012031

Speaker Country:

FORMABILITY / 91

Stamping evaluation of laser-welded blank (LWB) materials

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In this study, various AHSS LWBs and GEN3-980 monolithic blanks were tested using a universal forming tool (UFT) to characterize the global formability such as the maximum draw-depth, and local formability such as necking and weld cracking. Two different LWB fabrication orders between welding and hole-piercing were used to evaluate the effect of the fabrication order on formability.

Both the Same material same thickness (SMST) and the same material different thickness (SMDT) showed respectively about 40% and 30% reductions in the maximum stroke for the cutting-welding configuration compared to the welding-cutting configuration. The different material same thickness (DMST) showed a similar maximum draw depth regardless of the fabricating configurations because the strength difference between DP600 and DP980 may result in the necking on DP600 regardless of the weld quality. FEM predictions of the necking based on FLC were well correlated with experimental results for SMDT and DMST. However, the FEM prediction capability to simulate the SMST was limited without considering the weld mesh model and its properties. A better correlation was found between experiments for SMST and FEM predictions with the weld model.

Speaker Country:

TRIBOLOGY / 92

Experimental investigation of the effect of lubricant change on automotive component

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Manufacturing problems resulting from lubricant supplier changes are relatively common in automotive press shops. Computer-aided processes and tool design detect a significant proportion of manufacturing noises before tools are physically produced. In modern forming codes, an enhanced Coulomb model is used to numerically model the friction phenomena associated with lubrication. In laboratory conditions, determining model parameters through physical measurement is challenging. As a result, it became necessary to design a device that could be utilized in industrial environments. In this study, we present the prediction of a manufacturing problem resulting from a change in the lubricant of an industrial sheet metal part. The measuring device has been developed based on the parameters of the friction model of the lubricant materials. The developed measuring device may be used to determine the pressure- and velocity-dependent friction model parameters. The measuring device can only measure a limited range of pressures and velocities, so the results are extended to wider range using a mathematical method. The results demonstrate the effect of lubricant material changes on the forming process using the AutoForm code.

FORMABILITY / 93

Truth and misbelief of the biaxial bulge testing

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The material flow stress is one of the important input data for accurate numerical modeling of sheet metal forming. The standard uniaxial tensile test is widely accepted to characterize the flow stress of sheet metals. However, the range of strain obtained from the tensile test is usually limited to define the material plastic behavior for sheet metal forming. Therefore, the biaxial bulge test is often used to obtain a larger range of accurate flow stress instead of extrapolating the tensile test data. With the use of Digital Image Correlation (DIC), a more accurate technique was developed to determine the flow curve at large strains compared to the conventional analysis method. This study introduces the advantages and limitations of the bulge test and the corresponding DIC data analysis techniques in obtaining reliable flow data at extended strains.

Speaker Country:

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 94

Microstructural evolution of Usibor@1500, Usibor@2000 and Ductibor@1000 using dilatometer and in-situ studies for a simulated hot stamping condition

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Press hardening grades are widely used in automotive industries for safety-critical structural parts due to its unique combination of high strength, excellent formability, and crash performance. Although general process windows are recommended by steel suppliers, achieving the targeted strength and ductility / fracture strain in the hot-stamped parts is still challenging to some hot stampers for some grades. In this investigation, a dilatometer study for Usibor@1500 and two emerging grades Usibor@2000 and Ductibor@1000 under hot stamping condition was conducted with consideration of the entire hot-stamping processes (i.e., austenitization, blank transfer, forming and final quenching) to understand the differences in critical cooling rates, and evolution of microstructures. Influence of forming strain on final properties is also examined for Ductibor@1000 by DIL 805 A/D dilatometer under tensile deformation mode. In-situ observation of microstructural evolution during hot stamping process is explored using Confocal scanning laser microscope to further fine-tune customer hot stamping practices.

Speaker Country:

FORMABILITY / 95

Characterization of local formability for cold rolled AHSS with 780MPa tensile strength

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As advanced high strength steel (AHSS) for automatic light-weighting increases, different properties of steel are required for each component.
In addition to global formability, it is important to understand the characteristics of local formability more.
Local formability was investigated for four steels with two or more phases of the same TS 780 class.
Hole expansion test and bendability representing local formability were examined.
HER evaluation was conducted with ISO standards, and HER was evaluated according to the influence of hole size.
The degree of improvement of HER was confirmed for four steel types through double punching.
Also, to verify the fundamental formability of the material,
HER was obtained under hole processing conditions through machining excluding the influence of hole punching.
In the bending evaluation, a continuous bending test of VDA was performed
It was confirmed that the effect of trimming at the edge differed by steel type in the bending test.

FOSSIL-FREE STEEL, SUSTAINABLE MATERIALS, AND MATERIAL FORMING / 96

The effect of trace elements on the properties of a fossil-free formable low-alloyed steel grade

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The present intention to reach fossil-free steel manufacturing will inevitably result in an increase in the use of steel scrap as a raw material for steel production. Consequently, the amounts of elements, seen as impurities, will increase in steels. This has already been seen in electric arc furnace (EAF) processed steels, where the Cu and Sn levels have doubled in some cases after 1980's. This may cause problems, as it is well-known, that some impurity elements have harmful effects on the properties of steel. This has been widely studied in low-alloy steels containing chromium and molybdenum which are widely used in components for the petroleum and electrical power generation applications. However, limited number of studies have been performed on formable steel grades, and the published reports/articles have mostly concentrated on the effects of P and B. Thus, there is still a need to understand the roles of other impurity elements. In the present study, a formable C-Mn steels containing additions (either individually or in combination) of Cu and Sn is investigated. The samples were cold rolled and annealed following typical time-temperature profiles of modern continuous annealing lines. Mechanical and forming properties (incl. bending and cupping tests) are determined as well as elemental profile analysis is conducted. The results identify that minor additions of impurity elements, in this case Cu and Sn, does not affect the mechanical and forming properties of low alloyed formable steel grades considerably.
Key words: Cu-Sn alloying, GDOES, tensile tests, forming tests.

Speaker Country:

SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 97

Influence of process and material parameters on the twist springback prediction of a panel

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Both advanced high strength steels and aluminum alloys gained increasing popularity because of the constant effort to meet the social pressure of reducing the vehicle weight while keeping their safety. The ratio between material strength and weight is much higher when compared to other materials, while the ductility is similar. Thus, the high springback after forming is one of the disadvantages of these materials, particularly when exhibiting twisting and side wall curl, which are the two most difficult types of springback to control and compensate in die engineering.

This study analysis the influence of several material and numerical parameters on the prediction of the twist springback. The benchmark selected is the one proposed by the Numisheet 2022 Benchmark #1: Springback Prediction of Twist Die Panel [1], which considers a tool used by the A/SP (Auto/Steel Partnership) for springback analysis for several years. Two processing conditions were

considered: (i) blank holder force that constrains the metal flow and (ii) draw bead-like feature known as a stake bead, which changes the forming conditions from draw to stretch forming, at the end of the process. The modeling of the elasto-plastic behavior of the sheet materials uses a wide range of experimental data, provided by the benchmark committee for a DP980 steel and a 6xxx aluminum alloy. In addition to the effect of the sheet material on the springback, the effect of the following parameters is also analyzed numerically: (i) friction coefficient; (ii) beads; (iii) modulus of elasticity; (iv) work hardening law and (v) yield criterion. All numerical simulations were performed with the finite element in-house code DD3IMP.
The twist springback is larger in the steel in comparison with the aluminum alloy, which is in good agreement with the experimental measurements [1]. The process parameter that most affects the twist springback is the presence of the stake bead, reducing significantly the springback . In addition, the reduction of the friction coefficient and of the Young modulus also leads to an increase in springback. On the other hand, the yield criterion has little influence on springback.

Reference
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SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 98

Simulation of the cold forming process of a bipolar plate for a PEM fuel cell

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The energy transition towards sustainable mobility requires developing alternative propulsion methods to combustion engines. One of these alternatives is hydrogen-powered fuel cells. A key component that guarantees the energy performance and durability of Proton-Exchange Membrane (PEM) hydrogen fuel cells are the bipolar plates.
For transportation applications, bipolar plates are required to reduce the weight and volume as much as possible to increase the volumetric power density. This fact entails the unavoidable use of metallic bipolar plates, mainly made of austenitic stainless steel. Another aspect that influences the energy efficiency of the fuel cell is bipolar plates design. Thus, the optimization of its geometry requires the use of finite element software for the simulation not only of the channel design, but also for the analysis of the stress distribution and mechanical deformation produced by the forming process needed for their manufacture.
In this paper, simulations based on finite element method are used to numerically reproduce the cold forming process of metallic bipolar plates. The complexity of the bipolar plates design has led to perform a mesh sensitivity analysis to better understanding the spatial discretization errors. The aim is to optimize the parameters of the mesh that allows results to be mesh independent with an acceptable solver time. The parameters predicted by the finite element simulations are finally compared with experimental values, resulting in a fairly accordance.

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 99

Formability analysis of sandwich sheets though computing techniques

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Formability analysis of sheet metals is not a new process; even the significance of analysing formability of sheets is an important factor for the industrial applications. Sheet metals are sharing majority of application in various industries, in specific aerospace and automotive industries. For the last 30 years, researchers performed their works on the sheet metal and their forming behaviour by various experiments, numerical simulations, computational techniques and optimization techniques. In recent times, advancement in sheet metal forming analysis is being carried out by different computational techniques such as artificial neural network (ANN), Genetic Algorithm (GA), Fuzzy Logic (FL), Conventional Neural Network (CNN), etc. based on the level of impact of computational techniques, the present paper aimed to study the forming behaviour of metal-polymer-metal (MPM) sandwich sheet forming behaviour. This study will be focused on the ANN or CNN on for MPM sandwich sheets.

FORMABILITY / 100

Development of a Hot-forming Process to Retain the 3G-AHSS Microstructure and Mechanical Properties using Quenching and Partitioning Heat Treatment

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The third generation of AHSSs (3rd Gen-AHSS) offers a good combination of strength and ductility due to the different micro-constituents inherited in the base material microstructure. However, the as-received material needs to be formed at high temperatures to form different parts in the body-in-white structure (BIW). Forming at high temperatures is crucial to reduce the press tonnage requirements; however, that could impose phase transformation of the final product, which will result in different microstructure and, therefore, changes in mechanical properties (strength, bendability, and ductility). This work developed a quenching and partitioning (Q&P) intercritical heat treatment process to maintain the as-received third-generation advanced high-strength steel (3rd Gen-AHSS) microstructure. The influence of peak temperature, holding time at peak temperature, heating rate, quenching temperature, and partitioning temperature was investigated using a thermo-mechanical simulator system (Gleeble3500). Large enough coupons were heat treated using the thermal simulator, and the microstructure and mechanical testing results were compared with the as-received material. The yield strength, total elongation, and V-bend angle exceeded the as-received material properties, while the ultimate tensile strength was slightly lower than the as-received material by 9%.

Speaker Country:

FORMABILITY / 101

Investigations on Formability of Tantalum RO5200 Thin Foils: Bio Material

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Tantalum RO5200 (TaRO5200) is an excellent and new emerging Bio-material with
wide applications. The most important property of TaRO5200 is Osseointegration which helps in integration of direct structural and functional connection between living bone and the surface. The process of forming in at actual is a plastic deformation where in the material is transforming in permanently is some shape without occurrence of any type of defect of failure. Few different types of failure enlisted are local necking, wrinkling, earing etc. In recent days transforming from macro level to micro level is now trending part of life. The most difficult part in moving towards micro level forming which means forming of sheet under 100 microns is control over process. Hence this gives significance
and rise for the investigations over forming at micro level and prediction of mechanical properties at micro level. The research work posited in this paper focusses on the plotting of Forming limit curve (FLC) which is one of the methods to investigate formability of ultra-thin foil of TaRO5200 with sheet thickness 80 microns (μm). The experiments performed for FLC plotting were based on the Nakkajima test following the ASTM 2218-14 standards. The FLCs are plotted experimentally and via numerical simulation as well which in comparison shows a good agreement. The variance obtained between experimental and numerical simulation is up to 15%. Microstructural study is also performed on the specimen prior and after forming test to analyze and understand the physics along with mechanism of the material in test. The material behavior is also
explained in the microstructural study section

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRING-BACK COMPENSATION, AND GEOMETRY ASSURANCE) / 102

Numerical Simulation and Analysis of Tailored Tube Hydroforming

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Tube hydroforming (THF) is one of the most acceptable unconventional metal forming processes which is widely used to form various tubular components. In this process, tubes are formed into different shapes using internal pressure and axial compressive loads simultaneously to force a tubular blank to conform the shape of a given die cavity. The applications of THF are known in the automotive and aerospace industry where more intricate geometries formed from tubes and extrusions. They are characterized by the use of tubes, thus allowing an extended different variety of shapes. Now a day, the automotive industry is showing interest in THF. The benefits of THF can, for instance, be combined with the high strength of extra high strength steels, which are usually less formable, to produce structural automotive components which exhibit lower weight and improved service performance. Design and production of tubular components require knowledge about tube material behaviour and tribological effects during hydro-forming and how the hydro-forming operation itself should be controlled. These issues are studied analytically in the present paper. In this work, free bulge shaped tube die was modeled by using CATIA V5R20 subsequently, the processes were simulated using PAMSTAMP and it has been verified with numerical work under proper boundary and loading condition. Process parameters study also been conducted. It has been found that the wall thickness and the branch height are most sensitive to friction, axial load, and internal pressure.

FORMABILITY / 103

Numerical investigations to improve the final sheet thickness in the SPIF process of DC04 sheets

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Incremental sheet forming (ISF) is an innovative sheet metal forming technique. A small, incremental deformation forms a sheet into the final workpiece. The sustainable and futuristic approach is necessary to depute this technology in real world. Improved formability, minimal set-up cost, and flexibility are some of the major advantages of the ISF process. However, the key challenges are uneven sheet thinning, reduced surface roughness, and geometrical accuracy. The process parameters such as percentage step over, tool profile and toolpath are varied at three levels and the performance is measured in terms of final sheet thickness. The step over percentage was considered as 40%, 50% and 60% of tool diameter while, non-conventional tool paths such as zig with contour, trochoidal tool paths and conventional constant depth tool paths are considered. In addition, three profiles of the tools like flat with corner radii, hemispherical, and elliptical tools, were used in experiments. The ANOVA results show that the tool path is most significant factor followed by tool profile and the step over is observed to be insignificant factor. The z- level tool path and zig with contour tool path will offer higher sheet thickness of the resultant part.

Speaker Country:

India

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 104

Substitutive models of press deflections for efficient numerical die cambering

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Cost and time for die tryouts are significant within the car industry. A major contributing factor is that elastic deflections of dies and presses are usually not considered during the virtual die design and forming simulation phase. Active surfaces of stamping dies are only cambered based on previous experiences of tool types and presses. However, almost all stamping dies and presses are unique, and available experiences are not valid for new materials. This leads to component deviations and often several loops of tool adjustments are needed. Previously partners within the SMART Advanced Manufacturing research project CAMBER have develop advanced deflection measuring devices to quantify the elastic deformations of presses. Using these measurements, cambering methodologies can be utilized in sheet metal forming simulations. In this paper numerical substitutive press models are described which are capable of compensating for measured press dynamics. The result show that a numerical compensated tool can show an improved contact by over 50%.

Speaker Country:

Sverige

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 105

Development of geometry variants and forming technology for metal diaphragms to increase the efficiency of diaphragm compressors

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Keywords: Diaphragm compressor, metal diaphragm, single point incremental forming
Abstract.
This article deals with the development of an elastically foldable, bistable diaphragm geometry, which allows an increase of the compression volume of diaphragm compressors compared to the use of flat diaphragms. Using a Finite Element Model (FEM) in ABAQUS/Standard, a number of membrane geometries (truncated cone, hemisphere, cone and dome) were calculated and analyzed with regard to elastic deformation. Selected geometries were produced by Single Point Incremental Forming (SPIF) and tested by applying full-area pneumatic pressure to determine the diaphragm lifetime.

Speaker Country:

Germany

TRIBOLOGY / 106

Tribological investigations of water-based lubricants for application in the deep drawing process

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In times of scarce raw materials, the concept of alternative lubricants occupies a special role. In this context, water-based lubricants offer many advantages over mineral oil-based lubricants in terms of disposal, handling and savings. However, water alone is not suitable for lubrication in industrial environments due to its physical and biological limitations, so additives must be added. For this reason, lubricants based on mineral oils and additives are mainly used in today's practice. Various manufacturers already have water-based lubricants in their catalog. These lubricants are described as particularly sustainable because they are easy to dispose of compared to mineral oil-based lubricants.

This paper describes the tribological investigation of water-based lubricants in the context of a deep drawing process. Therefore, different methods were conducted in order to determinate the suitability of these lubricants for a deep drawing process. Three lubricant manufacturers each provided their lubricants as part of this work. The sheet materials investigated are an aluminum material (AA6014) and three steel materials (DC04, DP800, 1.4301), each with a thickness of 1.5 mm.
All sheet materials were examined in the as-delivered condition as part of this work. The hypothesis for this research proposal is that it is possible to achieve comparable tribological properties in sheet metal forming using water-based lubricants as when using mineral oil-based lubricants. The aim is to optimize a tribological system for water-based lubricants when used as additional lubrication in order to replace mineral oil-based lubricants and, as a result, to shorten the representative process chain by one process step (cleaning).
In the course of this work, topographical measurements of the sheet materials were carried out in order to investigate the lubricant holding capacity of the sheet materials. Furthermore, strip drawing tests were performed to determine the friction coefficients of the different lubricant-sheet combinations. The final step was to conduct deep-drawing tests to determine the limits of use of the water-based lubricants by continuously increasing the holding-down force.

Speaker Country:

Germany

FORMABILITY / 108

Effect of the intercritical annealing in the formability and microstructure of a medium Mn steel sheet

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A medium Mn steel was fabricated by employing a vacuum induction furnace. After that, the steel was hot rolled in order to achieve a final thickness of 1.5 mm. The resultant microstructure of the sheet was composed of martensite and very little amount of austenite, the ultimate tensile strength in this condition was close to 1600 MPa with a negligible elongation. An intercritical annealing was designed and proposed to promote the austenite reversion and to increase the amount and stability of this phase. Thermodynamic simulations and previous experimental results were used to determine the temperature and time for the heat treatment. After intercritical annealing, the steel exhibited a elongation close to 30% and a UTS close to 1200 MPa. Formability testing was carried out in that condition in order to correlate the microstructural changes experienced by the sheet with the formability results

Speaker Country:

MEXICO

FORMABILITY / 109

Experiments and simulations of the drawing envelope of pure aluminum

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The range of blank-holding force (BHF) for which successfully forming of AA1100 in three different tempers is investigated using a combination of experiments and analysis. The experiments involve circular blanks of three different diameters: 35 mm, 37 mm and 40 mm. The thickness of the blanks is 0.51 mm. These are drawn with a punch of 20 mm diameter, i.e., at drawing ratios of 1.75, 1.85 and 2.0, respectively, using a custom, modular forming apparatus where the BHF can be controlled at will, between 0 and 2,400 N. The experiments are performed in an Instron 8872 servohydraulic frame, so that precise measurements of punch force and displacement are available. The working envelopes are determined experimentally in this way. It is found that grey zones exist between the wrinkling, safe and tearing regimes. These experiments are then simulated in Abaqus/Standard, using two types of models: axisymmetric and shell. In the latter case, plastic anisotropy is included using the Yld2000-2D anisotropic yield function. Wrinkling and tearing failure are induced using geometric imperfections: a circumferential random wave in the flange for the former (shell model) and a thickness reduction for the latter (axisymmetric and shell models). It is shown that the models are able to reproduce the experiments well. This serves as a verification of the modeling framework, so that is can be used for simulations of more complex forming.

Speaker Country:

USA

FORMABILITY / 110

An Efficient Methodology to Characterize Formability of Aluminum Sheet using Nakazima and Marciniak Tests

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Keywords: Formability · Non-linear strain path · Aluminum · Anisotropy· Contact Pressure
Characterization of the in-plane forming limits remains a central aspect of alloy development and is critical for the virtual design of forming operations. Nakazima formability tests represent the most commonly used test method but have so-called process effects of out-of-plane bending, contact pressure and non-linear strain paths which serve to inflate the limit strains compared their in-plane values obtained using Marciniak tests. A methodology to remove the Nakazima process effects has been proposed in recent years but has seen limited application to high strength aluminum alloys. The sensitivity of the process corrections to the limit strain detection method also remains unclear. To these ends, two 6xxx-series automotive aluminum alloys in the T4 temper were selected to characterize formability in selected Nakazima and Marciniak tests. A novel approach using a miniature tensile test and stereoscopic digital image correlation (DIC) is used to efficiently characterize the anisotropic hardening behavior which is required for the contact pressure correction. Four different limit strain detection methods were considered: the ISO12004 method; the linear best fit (LBF) method; a temporal method using the second derivative of the strain rate and a novel curvature-based method. The choice of detection method is shown to have a marked effect upon the process corrections, particularly when the limit strain has been identified late in the process after the instantaneous strain path has shifted towards plane strain. Finally, the corrected limit strains are contrasted with analytical predictions of the forming limit curve under plane stress, in-plane stretching conditions.

Speaker Country:

Canada

FORMABILITY / 111

Influence of elevated surface temperature on the formability in cold forming of aluminum alloy sheets

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In recent decades deep drawing of 5xxx and 6xxx aluminum alloy sheets has increasingly been applied for producing lightweight car body components. Because of frictional heat the surface temperature of the drawing tools may notably increase during series production of these components, even though the deep drawing process is basically performed at room temperature. This work investigates the influence of elevated temperatures on the formability of commercial dry-lubricated 1.5 mm-thick EN AW 5182 and EN AW 6016-T4 sheets. Therefore, deep drawing experiments using a cross-shaped tool were performed at different surface temperatures between room temperature and 100 ℃. The results of the experiments revealed that the drawing depth – which can be considered as indicator for the formability – decreases as the temperature of the contact surfaces increases. This trend was confirmed by friction testing using a pin-on-plate tribometer. The results clearly showed that the coefficient of friction (COF) significantly increases at elevated temperatures.

Speaker Country:

Austria

FORMABILITY / 112

Design of an In-Plane Shear Test for Fracture Characterization of High Ductility Metals

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Fracture characterization of automotive metals under simple shear deformation is critical for the calibration of advanced fracture models employed in forming and crash simulations. Great strides in shear fracture characterization have been made over the past decade with several novel geometries proposed. However, in-plane shear tests of high ductility materials have proved challenging since the edge fails first in uniaxial tension before the shear fracture limit is reached in the center of the sample. Although through-thickness machining is undesirable, particularly for extrusions and castings, it appears required to promote higher strains within the shear zone to avoid edge cracking in materials where the shear fracture limit significantly exceeds that of uniaxial tension. The objective of the present study is to adapt existing in-plane shear geometries, which have otherwise been successful for many automotive materials, to have a local shear zone with a reduced thickness. It

is demonstrated that a novel shear zone with a shape resembling an infinity sign or “peanut” can promote shear fracture within the shear zone while reducing the risk for edge fracture. Detailed finite-element analysis was performed to select the shear zone shape and thickness reduction with an emphasis placed upon machinability. Mild and advanced high strength steel sheets were then tested using the conventional and modified shear geometries with digital image correlation techniques utilized for strain measurement. For the mild steel, the conventional shear geometry failed prematurely at the edges while the equivalent strain in the modified geometry reached levels of 400%.

Speaker Country:

Canada

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 113

Flexible roll forming of high strength automotive components.

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Flexible Roll Forming (FRF) is an advanced manufacturing process that can be used to form long and complex part families from hard to form materials for the automotive and truck industry. However, depending on the part complexity and material strength shape defects such as end flare, springback and twist can occur. In this work a high strength truck member (frame rails) is produced from AHSS; the complex component combines shape variations in width and depth. To overcome flange wrinkling a new forming approach is introduced that includes the forming of a top hat shape to provide an additional stiffness in the flange edge. In addition to this a flexible over forming technique is applied to overcome end flare and springback. The experimental results are evaluated and discussed with numerical analysis and suggest that the presented forming technology enables the manufacture of high strength components in accordance to automotive specifications and quality standards.

Speaker Country:

Australia

TOOLS AND DIES / 114

Wear characteristics of the tool in the cold stamping process of ultra high strength steel sheet by establishing a novel wear test method based on the progressive die

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Demands for lightweightening and crashworthiness of the vehicle body have increased. For this purpose, advanced high strength steel to the automobile body was regarded as a solution with respect to manufacturing cost and impact energy absorption. However, increasing the strength of the automotive steel sheet lead to a diversity of problems caused by the tool wear due to higher forming load than that of commonly used steel sheets. Hence, systematic wear experiment and evaluation methods are required to quantitatively and qualitatively evaluate the tool wear amount in the sheet metal forming process. In this study, a methodology is proposed to quantitatively evaluate the wear of sheet metal forming tool based on the experimental results. In order to carry out a systematic wear test and save the time and cost, the progressive die set was designed to be suitable for wear test. The designed testing machine can simultaneously test four types of punches made under various tooling conditions such as materials, shapes, and coatings. Through the measurement of the wear depth, roughness, and surface imaging of the punch and product roughness, which represent the wear characteristics, quantitative evaluation methods for tool wear in the sheet metal forming process are established. By referring to the wear test results, it is confirmed that it is appropriate to analyze the reasonable tool wear characteristics by using the proposed methodology for quantifying the tool wear in the sheet metal forming process.

Speaker Country:

Republic of Korea

FORMABILITY / 115

Experimental Characterization and Prediction of Forming Limit Diagrams of PHS1800 During Hot Stamping

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The use of press-hardening steels (PHSs) in automotive bodies creates the opportunity of producing thinner but higher-strength components. PHS1800, a grade of PHSs with a strength level of around 1.8 GPa after hot stamping, is a candidate material for vehicle anti-intrusion structures. The current study aims to investigate the formability of this steel during the hot-stamping process. A novel experimental methodology was developed to characterize the Al-Si coated PHS1800 formability using a custom Marciniak punch and digital image correlation (DIC) techniques. The carrier blank thickness and geometry were exploited to quench the surrounding material of the specimens while promoting localization in the central regions. The proposed methodology provided approximately linear strain paths from uniaxial to biaxial stretching while avoiding friction and out-of-plane bending. The forming limit curves (FLC) of the material under various hot-stamping conditions were predicted using the Marciniak-Kuczyński (MK) model, taking into account the temperature and strain-rate histories. The predicted limiting strains were in good accord with the measured data.

Speaker Country:

Canada

SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 116

Deformation Prediction of Titanium Alloy in Incremental Sheet Forming with Anisotropic and Asymmetric Yield Function

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The present study is concerned with the prediction of deformation in incremental sheet forming (ISF) for a Ti6Al4V sheet. To investigate anisotropic and asymmetric behaviors, uniaxial tension and compression tests were conducted along the rolling direction (RD), diagonal direction (DD), and transverse direction (TD). A representative yield function for a HCP material, the Cazacu–Plunkett–Barlat (CPB06) yield criterion, was selected for constitutive modeling to take into account anisotropy/asymmetry-induced distortional yielding of the titanium alloy. The chord modulus degradation was confirmed through uniaxial loading–unloading tests. The ISF tests were carried out using a single contact-point tool following a truncated pyramid tool path. To predict the deformation during the ISF, finite element analyses were conducted with the ABAQUS explicit and the vectorized user-subroutine (VUMAT). The performance of various constitutive models was evaluated based on the comparison of deformed shapes and distribution of thickness from the experiment and the FEA.

Speaker Country:

South Korea

FORMABILITY / 117

Automated Nakazima and Marciniack experiments for studying loading path dependence of necking

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Forming limit experiments such as the Nakazima and Marciniak tests are important for the development of accurate sheet metal necking models. However, the testing procedure is time consuming. As a consequence, few experimental campaigns combine different material orientations and pre-straining experiments. We present an automated device for high-throughput FLC testing. Stereo digital image correlation is used for strain calculations, while a machine learning-based algorithm is used to detect crack initiation. The machine is equipped with an automated specimen charger holding 35 specimens. Various aluminum alloys and steels are tested in up to five orientations from the rolling direction. Pre-straining are performed at two strain levels, under uniaxial (0°, 45° and 90° from the rolling direction) and equi-biaxial conditions. Forming Limit Curves as a function of the loading path are presented and discussed in detail.

Speaker Country:

Switzerland

DIGITAL TRANSFORMATION, DIGITALIZATION, SMART PLANTS, SMART PRESSHOPS / 118

Monitoring of Deep Drawing Processes using Digital Twin-Based Sensors integrated in Tool Clamping Surfaces

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Process monitoring in forming technology can serve as a basis for transparent manufacturing and closed-loop control systems. Particularly, sensor systems associated with tool clamping interfaces offer great potential for robust inline process monitoring. However, the direct evaluation of only one sensor or even pure sensor data is hardly sufficient or not possible due to complex interdependencies at the tool clamping interface.
In this paper, a concept to monitor deep drawing processes combined with digital twin-based approaches for virtual sensors is introduced. Here, sensors integrated into tool clamping surfaces in forming machines are enhanced by a digital twin representing the elasto-mechanical behavior of the tool clamping interfaces during the deep drawing. Moreover, strategies to identify digital twins and their transfer to evaluation algorithms are highlighted. The resulting approach is not only covered by simulative analysis but also by experimental investigations.

Speaker Country:

Germany

FORMABILITY / 119

Chemical and Structural Banding in Q&P Steels: Design of Microstructure and Mechanical Behavior

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Quenched and Partitioned (Q&P) steels are designed to be high strength, while maintaining good formability for weight and cost savings in vehicle design. These steels are alloyed with C and Mn, for austenite stabilization, and Si for carbide suppression. It has been well established that Mn banding will occur during solidification of steels, as Mn has low solubility in δ-ferrite and will be partitioned into the liquid as solidification occurs, ultimately leaving regions of the microstructure with high and low Mn compositions. Here, an analysis of the chemical banding present was performed. Compositional modeling was leveraged to inform retained austenite fractions expected after heat treatment. Experimentally, a pre-treatment was leveraged to eliminate the structural banding present by homogenizing the carbon through the microstructure. Samples in which structural banding was present exhibited higher ultimate tensile strengths, however exhausted austenite transformation early during straining with one, low stability, austenite observed. Additionally, those in which structural banding was eliminated exhibited lower ultimate tensile strengths, and a more consistent transformation during straining indicating a broader range of austenite stabilities present. The results indicate the ability to use process design to tailor austenite stability for enhanced properties.

Speaker Country:

United States of America

SIMULATIONS (INCL. MATERIAL MODELS, TOPOLOGY OPTIMIZATION, TRIBOLOGY, SPRINGBACK COMPENSATION, AND GEOMETRY ASSURANCE) / 120

Evaluation of Anisotropic Material Models using the Flat Punch Hole Expansion Test

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The accurate calibration of constitutive models is critical for the virtual design of stamping of lightweight automotive components using finite-element modelling. Anisotropic plasticity models are commonly calibrated using uniaxial and biaxial tension test data under the assumption of plastic incompressibility and an associated flow rule. However, the deviatoric stress states under which plane strain conditions occur are often left unconstrained in the yield function calibration. This can be problematic since plane strain tension governs thinning, localization, and fracture in many forming operations. The flat punch hole expansion test can be used to evaluate the calibrated yield function across all directions under plane stress conditions. The local deformation can be measured using digital image correlation (DIC) and directly compared with the simulation predictions. The objective of the present study is to propose an efficient calibration and characterization methodology for anisotropic plasticity models that adhere to associated deviatoric plasticity. A host of automotive steel and aluminum alloys with a wide range of anisotropy and hardening characteristics are considered. The tensile hardening behavior is experimentally characterized to large strains using stereo DIC from specimens having a gage width less than six times the sheet thickness. A straightforward inverse analysis approach is adopted to characterize the plane strain yield strength from notch tests with a correlation proposed in terms of the tensile R-value. It is demonstrated that by applying a deviatoric constraint for plane strain tension during the calibration process, the strains and thinning distributions can be well predicted in the hole expansion test.

Speaker Country:

Canada

SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 121

FE simulation of springback prediction in U-draw bending with the simplified distortional hardening model

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The distortional hardening model has been widely used to describe the nonlinear behavior such as Bauschinger effect, permanent softening, and nonlinear transient behavior. Unlike the kinematic hardening model, the distortional hardening model mainly adopted the rotation and contraction of the yield surface under plastic deformation and showed the higher accuracy than the kinematic hardening model. However, the formulation of the distortional hardening model is getting complicated for the accurate prediction of material behavior under nonlinear strain paths. In this research, the

simplified distortional hardening model has been introduced for the sheet metal forming simulation. The verification of the proposed simplified distortional hardening model has been conducted with nonlinear strain paths for advanced high strength steel and aluminum alloys: Tension-Compression and two successive tension with different loading direction. The springback prediction in U-draw bending has been performed with the simplified distortional hardening model. The accuracy and time efficiency of the proposed model has been compared with the Homogeneous Anisotropic Hardening model and the isotropic hardening model. The proposed model showed the accurate prediction as the HAH model and comparable time efficiency as the isotropic hardening model.

Speaker Country:

Republic of Korea

LIGHTWEIGHT STRUCTURES / 122

Multi-functional SMC-aluminum battery tray to drive lightweight design

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Functional integration and lightweight design are important tasks especially for modern electric vehicles. Development of multi-functional assemblies for the battery box of the future is one of the challenges in the field of electric mobility. The housing must perform many tasks: structural stiffening and sealing (waterproofness) as well as crash protection and thermal management for the batteries.
In this paper results from a new developed multi-functional assembly of a SMC-aluminum battery tray will be presented and discussed. The outer housing shell is SMC formed and joined at the same time with the aluminum foam component. Furthermore, passive thermal management functions are integrated into the sandwich core realized with switchable air-cooling and phase-change-material integrated into the foam. Additionally, sensors for structural health monitoring, temperature and humidity sensors are integrated. The battery frame is designed to withstand impacting parts (vehicle parts, bollard, pole, stones, etc.), in the event of a crash using a sandwich structure with an aluminum foam core, one aluminum and one FRP cover sheet.

Speaker Country:

Germany or Sweden

TESTING, TESTBEDS / 123

An ultra-low temperature cooling system and evaluation technology for the aviation aluminum alloy sheet cryogenic forming test

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The requirements of high reliability, long life and lightweight in aerospace field have been greatly improved. It is urgent to replace the tailor-welded structure with integral one. Aviation aluminum alloy with light weight and high strength has been applied to a class of thin-walled curved parts with integral structure. However, compared with the conventional aluminum alloy, high strength aviation aluminum alloy has poor formability at room temperature. Usually wrinkle and fracture defects can be found in the thin-walled curved parts after deformed.
Based on the phenomenon of plasticity and strength increase simultaneously of aluminum alloy at ultra-low temperature, Cryogenic forming technology was proposed. The thin-walled components can be manufactured by cooling the blank to a certain low temperature range with coolant. The advantages of formability improved significantly, microstructure and mechanical properties controlling easily make the technology friendly to industry.
Compared with the conventional low temperature box combined with mechanical properties testing instruments, the one that can evaluate the formability of materials under ultra-low temperature conditions is not reported. In order to study the complex process coupled temperature and stress in cryogenic forming, and the deformation behavior of aluminum alloy sheet under the same conditions, an ultra-low temperature cooling system is built based on Gleeble3800 simulator with ultra-low temperature refrigerator. The ultra-low temperature formability of aviation aluminum alloy is evaluated by spherical bottom drawing. This work helps to promote the application of cryogenic forming technology.

Speaker Country:

China

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 124

An efficient pre-hardened cryogenic forming process for AA7075 aluminum alloy sheets

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Currently, due to the requirement of lightweight in the transportation field, the demand for high-strength aluminum alloy is increasing, but it is difficult for the traditional forming processes to balance the three components of formability, strength and efficiency. In order to solve this problem, a novel stamping process for high-strength AA7075 aluminum alloy sheets is proposed, termed Pre-hardened Cryogenic Forming (PCF) process. PCF process is to fulfill simultaneously the demands of good cryogenic formability and high post-formed strength through a suitable ratio of microstructure between the solution-treated matrix and the pre-aged second phases, thereby cancelling the additional artificial aging treatment and achieving high-efficiency. The good cryogenic formability is assured by solution-treated matrix, while the initial strength and further artificial age-hardening during paint baking are regulated by means of pre-aged second phases. A critical issue for PCF process is to determine the pre-aging process window, i.e., a suitable combination of pre-aging temperature and time period. The results show that pre-aging at 120 ℃ for 1h can achieve excellent comprehensive mechanical properties of cryogenic plasticity and post-baking strength, where the mixed structure of the GP zones and the η' phases for PA-120-1h alloy is the suitable combination of strengthening precipitates for balancing cryogenic plasticity and post-baking strength. In addition, based on the newly-designed cooling system (cooling channel and local spraying for LN2), stamping tests are conducted on a W-shaped beam component to verify the engineering feasibility. The cryogenically stamped W-shaped components show good surface quality and uniform thickness distribution. The final post-baking strength exceeds 92% of the tensile strength of AA7075-T6 alloy

without extra heat treatment, and the thickness reduction rate is within 10%. Regardless of the immersion time of the sheets in liquid nitrogen, the PCF process can be finished within 2 min, greatly improving the forming efficiency.

Speaker Country:

P.R.China

FORMABILITY / 127

CRASHWORTHINESS EVALUATION OF PRESS HARDENED STEELS WITH DIFFERENT LATH-LIKE MICROSTRUCTURES

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The deployment of Press Hardened Steels (PHSs) in the Body-In-White structures that took place during the two last decades is at the origin of a breakthrough weight saving on vehicles while guaranteeing the safety requirements of the automotive industry. The production of parts with complex shapes and a high strength between 1500-2000MPa was made possible by taking advantage of the hot rheology of austenite combined with the fast cooling obtained by in-die quenching leading to auto-tempered martensitic microstructures.
In the present work, 22MnB5 was hot stamped with different thermomechanical processes to promote different lath-like microstructures (bainite, tempered martensite…). An innovative approach is proposed to link the complex microstructures formed between thermoregulated dies to the mechanical behaviour and local ductility of these materials during crash-like solicitations. The microstructure has been characterised through a multi-characterization technique approach including light optical microscopy, scanning electron microscopy, X-ray diffraction and electron back scattered diffraction. The local ductility is assessed with a combination of crack initiation tests (bending, notch tensile test) and crack propagation tests (Essential work of fracture). Despite similar microstructural crystallographic features, lower bainite and auto-tempered martensite can lead to very different strength – local ductility compromise.

Speaker Country:

Spain

COLD AND HOT FORMING AND TRIMMING (INCL. SINGLE AND MULTI-STEP FORMING) / 128

Development of Rapid Die Cooling Technology to Reduce Cycle Time in Hot Stamping Process

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Recently, the automobile industry is increasing demand for hot stamping parts due to the growth of eco-friendly vehicles with the lightening and the crash safety performance. In the hot stamping process, a high-temperature heated steel sheet is simultaneously stamped and quenched to manufacture ultra-high-strength components of 1.5GPa or more. However, it takes more than 10 to 15 seconds to meet dimensional quality and mechanical properties during stamping. For this reason, it has the disadvantage of poor productivity compared to cold stamping. Moreover, the hot stamping component has a difference in cooling behavior depending on the geometry position. In particular, during deep drawing with a large deformation, the contact pressure is decreased due to the decrease in the thickness of the sidewall of components, and thus the cooling speed is significantly decreased. Therefore it can be said that the production cycle time of hot stamping components is determined according to the cooling performance of the sidewall. In this study, the groove pressing was applied to the sidewall of the die to increase the contact pressure and improve the cooling rate. Then, the cooling performance according to the groove shapes was evaluated through a hot stamping simulator, and the changes in dimensional quality and mechanical characteristics were analyzed together. In addition, the Cyclic Corrosion Test (CCT) was verified to see if there was any problem with corrosion resistance on the surface of the component where the groove pressing was applied.

Speaker Country:

Republic of Korea

SPRINGBACK, SHAPE ACCURACY, GEOMETRY ASSURANCE, AND SURFACE QUALITY / 129

Defects from bending finite thickness sheet over developable surfaces

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A developable surface is one that can be flattened into a plane without distortion. Thin sheet metal is often treated as a developable surface. The classical theory of folded developables proves that curved crease, origami-style folding can be applied to thin sheet metal of high strength to manufacture parts with rather complex geometries. However, its applications are found to be limited to sheet metal with low-medium strength and adaptation of various thickness accommodation techniques like grooving or perforation of the material at the fold lines. Removing material at the fold lines facilitates curved axis bending of rigid materials having finite thicknesses. Applying the geometrical concept otherwise, although has attractive applications in sheet metal intensive industries like automotive and transportation, remains unexplored. The current study tests the applicability of the theory of folded developables without compromising material integrity at the fold lines, by combining it with a traditional sheet metal forming technique called flange drawing. Following the theory, a developable connection is successfully achieved with a thin sheet metal material of high strength and reasonable inextensibility, without using any thickness accommodation techniques. However, it is found that the findings of the classical theory do not hold true for bending sheet metal having a finite thickness. The shape of the formed developable is not identical to the initial shape. Unique shape defects like curving and coning are identified. Additionally, a modified strain measurement method revealed significant membrane strains in the plane of the formed developable. A geometrically perfect model overestimates the magnitude of strains obtained analytically. Therefore, material properties and related effects like springback cannot be ignored as they not only influence deformation in the geometrical process, but also the shape of the final part. This knowledge adds value for designing future processes to manufacture complex sheet metal parts from developable shapes, using conventional forming techniques.

Speaker Country:

Australia

TESTING, TESTBEDS / 130

EXPERIMENTAL CHARACTERIZATION OF FORMING BEHAVIOR OF 3rd GEN AHSS

Authors: Elise Champolivier[1]; D. Brancherie[2]

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As automakers are challenged to improve safety and weight reduction, they continue to search for new solutions to meet the higher performance demands of body structures. The combination of the Laser Welded Blanks (LWB) technology with 3rd generation of Advanced High-Strength Steels (AHSS) for cold stamping is responding to that challenge. The new Fortiform® (3rd generation of AHSS) based LWB combines superior formability and ductility at higher strengths, thus opening significant new opportunities to reduce weight of vehicles while maintaining safety performances.The development of these new solutions could brings additional questions regarding part formability.
In this study, a Nakazima test is used to evaluate the forming behavior of LWB and estimate the Forming Limit Diagram (FLD). Tests are performed for several materials combinations of 3rd GEN AHSS in order to understand the influence of the weld on LWB formability. The experimental tools used are equipped with a Digital Image Correlation (DIC) system in order to measure strains distribution during the tests. We used a dedicated welding process to avoid Brittle Liquid Metal embrittlement and brittle behavior of the weld.Experimental results are used to determine the critical area during this forming test and a dedicated FLD for each material combination. The location of the onset of failure is investigated, from both optical observations, DIC data and modeling. It appears that various failure locations are obtained depending on both AHSS combination and strain paths.

In order to improve the accuracy of the determination of the onset of the failure, a method is under development to forecast the beginning of the instability.The improvement of failure prediction will be very helpful to analyze part formability and provide design recommendations.

Keywords: Forming Limit Diagram, Nakazima test, DIC, Laser Welded Blanks, 3rd Generation Advanced High Strength Steels

Speaker Country:

France

PLENARY TALKS / 132

Towards Virtual Tryout and Digital Twins at Volvo Cars

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Manufacturing Engineering Casting & Stamping within Volvo Cars is continuously evaluating, developing, and implementing new technology.
This presentation gives an overview of recent research and implementations in the area of simulations and virtual tryout of industrial dies.
Volvo Cars has also started the journey towards Smart Manufacturing & Digital Twins, an area with great potential and challenging research topics.

Speaker Country:

Sweden

PLENARY TALKS / 133

Sheet metal forming simulations at Volvo Cars: the past, the present and the future

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The paper will present the development of sheet metal forming simulations at Volvo Cars since the late 1980's until today. Major breakthroughs during the development will be presented as well as the current state of the art. Finally the future challenges for the sheet metal forming community, e.g. sustainable metals, and ideas how to solve these challenges will be presented.

Speaker Country:

Sweden

PLENARY TALKS / 134

SSAB's transformation to Fossil Free Steel with the HYBRIT Technology

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The topic of this plenary lecture is "SSAB's transformation to Fossil Free Steel with the HYBRIT Technology".

Speaker Country:

PLENARY TALKS / 135

Press hardening - History, and future

Author: Jan Larsson[None]

An Overview of press hardening applications and an attempt to look into the crystal ball. How does press hardening meet the challenges of our time?

Speaker Country:

PLENARY TALKS / 136

Perspectives on AI applications in sheet metal forming

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Special AI applications are gaining more and more importance as replacements for material models in metal forming and are used in manyareas of digital twins, such as soft sensors or predictive tools. The main advantage of AI models in this field is found by the capability of code of programming itself based on the simulated or experimental data provided, without the need for explicit programming.This keynote will present a choice of practical applications of AI in the field of sheet metal forming to reveal achieved readiness levels of today due to extended research.

Speaker Country:

Germany

PLENARY TALKS / 137

Novel and revisited experiments for plasticity and fracture testing of sheet metals

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The modeling of material behavior for both plasticity and fracture requires the development of increasingly accurate tests. On the one hand, the development of DIC allows to revisit tests such as the bulge test or the in-plane torsion. On the other hand, recent results show the enormous value of using robotics to perform mechanical tests. The benefits are an unmatched combination of speed, reliability, and cost-effectiveness in generating a complete set of experimental data leading to a full characterization within months to days.
This presentation will illustrate some of these advances in automated plasticity and fracture tests, mini-Nakajima plane strain tensile tests with dihedral punch, in-plane torsion tests at different strain rates, constant strain rate bulge tests, and high throughput Nakajima tests.

Speaker Country:

Sweden/France

PLENARY TALKS / 138

History of Hot Stamping process and hot stamping simulations

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With Luleå as the location of the conference, we will present to you the history of the press hardening process, the invention originated from Luleå. Together with the growing interest and use of the press hardening process, it came an increased need to predictand simulate the process. Something that has been developed here, and still is being further developed.

Speaker Country:

Sweden

PLENARY TALKS / 139

Optimal milling data preparation for draw dies

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Stamping simulation are accurately representing the reality today. Various quality requirements like splits, wrinkles but also springback and surface appearance are predicted. In orderto effectively execute the tryout process the process setup of the simulation has to be reproduced. However, the try-out process can be accelerated if specific information out of the simulation has been transferred in to the milling data preparation. In thepresentation an example will be shared how the milling data preparation can be optimized.

Speaker Country:

Sweden