

BEST PRACTICE METHODOLOGY FOR SPRINGBACK PREDICTION, COMPENSATION AND ASSEMBLY

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ABSTRACT. *Forming simulation technologies keep on developing at a rapid pace, to address formability, tolerance control, and product performance issues throughout an increasing range of processes, and in ever more detail.*

Springback prediction, die compensation and assembly simulation continue to evolve, with new concepts to improve the accuracy of springback prediction and compensation. Prediction is addressed both from the numerical methods perspective, for example, using enhanced material models with elasto-plastic springback, and from a process perspective, for example by the incorporation of geometric drawbeads. Die compensation highlights how the integration of simulation and geometry plays an ever more important role, both in terms of improving accuracy and reducing lead time.

Automotive components assembly processes include roll hemming and welding. The assembly simulation is the ideal solution for improving roll hemming, welding and the welding assembly processes, ensuring better part quality. The coupling of both stamping and welding simulation methodologies enables the user to optimize a complete manufacturing chain.

The overall industrial objective is moving rapidly from simple Draw-Die compensation, towards full 'line die' compensation, in particular, considering the influence of 're-striking' as a mean of springback control. Tool Compensation techniques are also being applied to flanging operations.

The question of springback prediction and compensation remains complex due to a significant number of influencing factors, especially the material's modeling. The evolution within material modeling must address not only new materials, but also new processes which are used to form these materials.

A car component is manufactured from different parts which are stamped, cast, bent, then connected and welded together to fit the welding assembly requirement.

The paper will discuss how the PAM-STAMP 2GTM integrated solution for springback prediction, compensation and roll hemming simulation and PAM-ASSEMBLYTM for assembly process design and validation are successfully implemented and coupled in industry to deliver a positive business impact on cost and quality, with emphasis on the Best Practices applied by users to different aspects of the prediction & correction methodology.

1. INTRODUCTION

The rapid and continuous development in computer hardware and software technologies such as DMP parallel computing sees manufacturing simulation playing an increasingly important role in vehicle development programs, helping to eliminate manufacturing risks, and to compress lead times on ‘critical path’ items such as large press tool manufacturing or parts assembly. This evolution has also resulted in the extended use of simulation, making it no longer the preserve of large companies such as OEM’s and Tier suppliers, but also finding use in smaller suppliers, and in ‘non automotive’ applications where previously the hardware and software costs, coupled with training and end user resources would have been prohibitive.

2. SPRINGBACK PREDICTION

The main advances in stamping simulation have been the extension of the domain in which the results are considered truly predictive and reliable. Just a few years ago, most of the discussions were about the validity of forming simulation methods, the competition between implicit and explicit solution schemes, and the comparison or validation of results based on strain distribution and thickness variations. In a relatively short period, we have moved on significantly. Largely the implicit vs explicit debate has gone away, with the realization that both methods have usefulness, and most software vendors are now utilizing both technologies.

The last few years have seen a real focus and debate on the prediction of distortions due to springback, and the accuracy with which forming simulation softwares were able to achieve this.

The focus is increasingly on driving simulation methodologies to model the entire forming process chain, cutting costs and time from the overall development process. It is fairly commonplace today for companies to simulate the full ‘die line up’ including re-striking and flanging die operations.

The overall objective of all this work is to arrive at the point, where it is possible to easily perform a predictive virtual panel quality assessment, such an assessment would of course include tolerance control; in respect of springback, ‘fit to gauge’, trim line accuracy, and in the case of skin panels or visible panels, then also cosmetic surface quality.

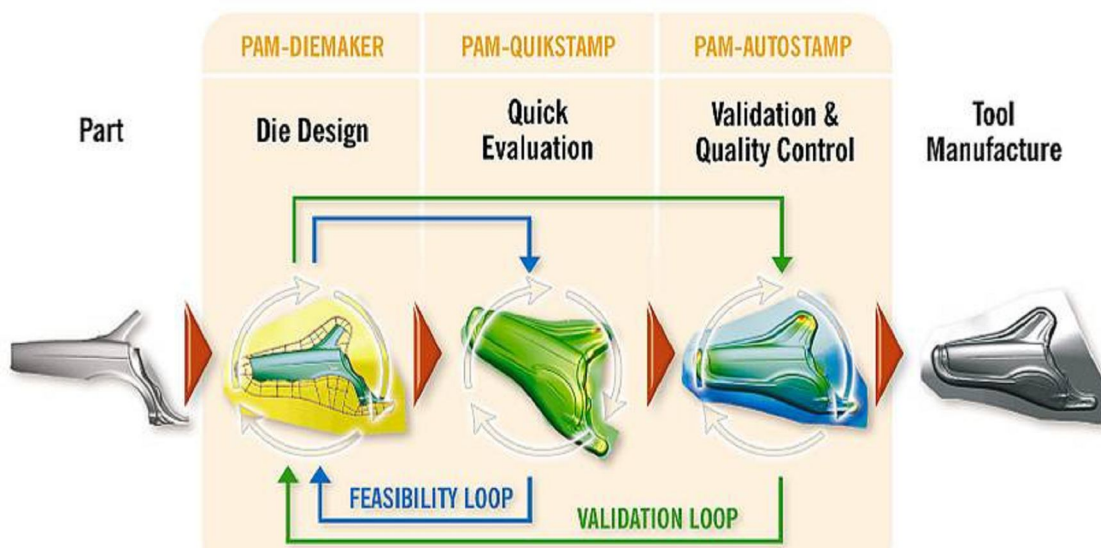


Figure 1. PAM-STAMP 2G value chain.

The topic of springback prediction is at the forefront in the field of stamping simulation software today. Compensation methods have been discussed at length for some time, but have only found use recently as springback prediction has come of age, and can be considered predictive, without this, even the best compensation methods would be futile.

The question of springback prediction remains complex, with a significant number of factors having influence.

2.1. Material evolution

In particular the advent of new material technologies, driven by the pursuit of weight saving and vehicle crash performance, has resulted in innovations such as ‘Dual Phase’, ‘TRIP’, ‘TWIP’, and ‘Complex Phase’ steels. This has rendered a lot of the ‘old school’ or experience based rules for springback control worthless, meaning that there exists now an absolute need to rely on simulation where experience can no longer solve the problems. In order to keep pace, forming simulation softwares have had to respond with developments in material modeling to reliably capture the behaviors of these new materials.

Until the advent of these advanced or ultra high strength steels, many companies did not really make use of springback prediction capabilities, preferring to solve the springback concerns during physical tryout, by process or die geometry adjustments, this however is simply not an option any longer, as the springback magnitudes witnessed from ultrahigh strength steels are very often greater than the thickness of the casting in the die face, this means that it becomes mandatory to ‘engineer a solution’ to the springback control mechanism, rather than to ‘solve the problem’ of springback under the press.

The evolution within material modeling has to cover not only new materials, but also new processes which are used to form these materials.

Cold forming material models have evolved to offer better Yield descriptions such as the Corus Vegter model, and also better hardening models, capturing Kinematic hardening effects such as the Yoshida model. Other advances have been the inclusion of damage and rupture models, though of course this has limited advantages for springback prediction.

Hot forming of Boron steels is becoming increasingly important, one of their major advantages being that they do not suffer with springback, though of course there are a number of other issues related to their forming which limit their use to a few crash critical components. Forming simulation has had to evolve to incorporate not only material models to handle this behavior, but also to describe accurately the heat transfer.

Other Hot forming processes such as superplastic forming are also successfully modeled using specific material models.

2.2. Geometry integration

The subject of springback compensation has been one of the biggest drivers to highlight the need for closer integration of Geometric data into simulation. Until recently it has been sufficient to begin with CAD definition and to perform forming simulation based on that definition, springback compensation however requires the modification of the geometry and its subsequent incorporation into simulation in an iterative process.

The need for geometry integration is not completely limited to compensation. Drawbeads for example have typically been modeled using equivalent models, these models account for restraining and opening forces, and may also impart changes in plastic strain and thickness to the blank, but they are not perfect, and do not capture all the effects evident with real drawbeads. Notably the flow of material through a drawbead section will inevitably result in some residual curvature in the material.

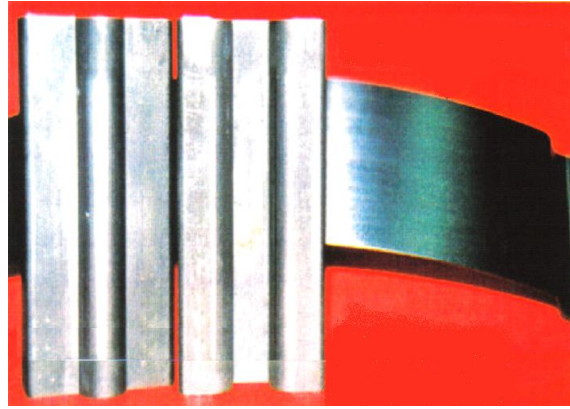


Figure 2. Residual sheet curvature after passing through bead.

This residual curvature, or curling effect, will have an influence in the springback in reality, in many cases it can be neglected as often the material affected by this phenomenon is removed during part trimming, however in cases where material passing through a drawbead ends up in the component itself, the effect must be considered. In order to capture the effect, it is becoming common practice to incorporate physical drawbeads in stamping simulation for such cases.

3. SPRINGBACK COMPENSATION

The last two years have seen all of the major stamping simulation software vendors releasing compensation functionality. The methodologies have evolved in partnership with Automotive OEM's and materials providers. Some significant early success has been seen, particularly in the smaller toolmakers, who have been the first to really embrace this technology and use it to their advantage, in many cases, being able to achieve correct component shape directly in the first tryout, after cutting dies to the predicted compensated shape.

Already in such a short space of time, the state of the art in die compensation is already capable of offering unique automatic, iterative compensation and simulation loops, which seek the minimization of deviation between the final part shape and the desired or target shape, the study being deemed to have converged once a given area (typically 95%) of the part is within the desired tolerance.

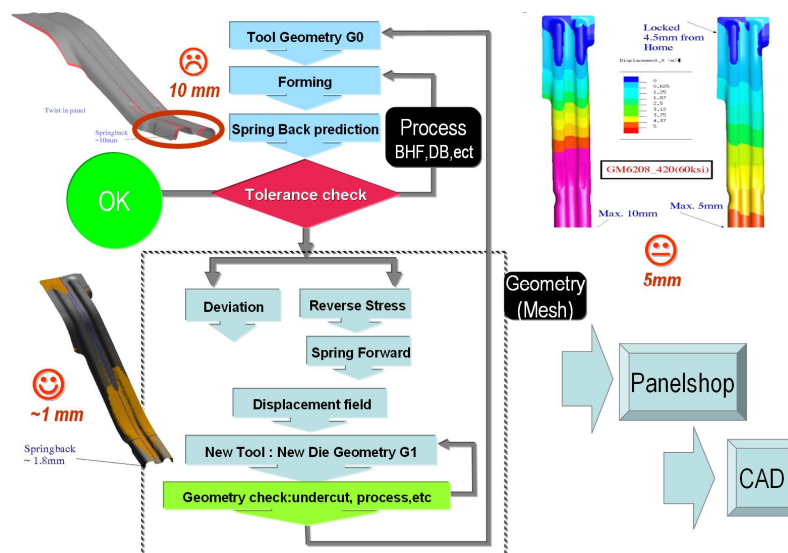


Figure 3. Die compensation iterative process.

But simulation results are not sufficient to fit OEM's, Tier suppliers and tool builder's needs.

The tool shape compensation methodology is based on modifications to the die mesh. While this is certainly the best approach for performing iterative loops within a simulation based environment, it still leaves the following problem: at the end of the compensation process, the user has a modified tool mesh, whereas he really needs a CAD model. Surface reconstruction has to be performed to be able to manufacture the compensated tools.

In order to address this issue, ESI-Group in partnership with iCapp, now provides the tools necessary to transform the modified tool meshes back to CAD.

On the other hand, compensating first drawing operation is useful but may not be sufficient for more complex parts as door inner which require more than one forming operation. Full die line compensation is on the way.

4. ROLL HEMMING SIMULATION

Hemming is the last or one of the latest stage operations used in the automotive industry to join inner and outer closure panels together such as hoods, doors, tailgates, etc. The bending/folding process moves the flange of the outer panel over the inner one. Current industry trends are going away from press and table top hemming, towards an increasing dependence on Roll hemming.

Roll hemming uses a standard industrial robot integrated with a roller hemming head to provide a flexible solution to closure manufacture. The flange of the outer panel is bent over the inner panel in progressive steps by means of the roller hemming head. The process allows the advantage of using the robot controlled hemming head to hem several different components in a single cell. Minor changes and modifications to panel hemming conditions can also be accommodated allowing a quick and cost-effective reaction.

The accuracy of the hemming operation affects significantly the appearance of the car's outer surfaces and has therefore a critical importance in the final perceived quality of assembled vehicles. New pedestrian safety targets also add further constraint to the desired shape of a final hemmed joint.

Moreover, designing the hemmed union is not always easy and is deeply influenced by the mechanical properties of the material of the bended part.

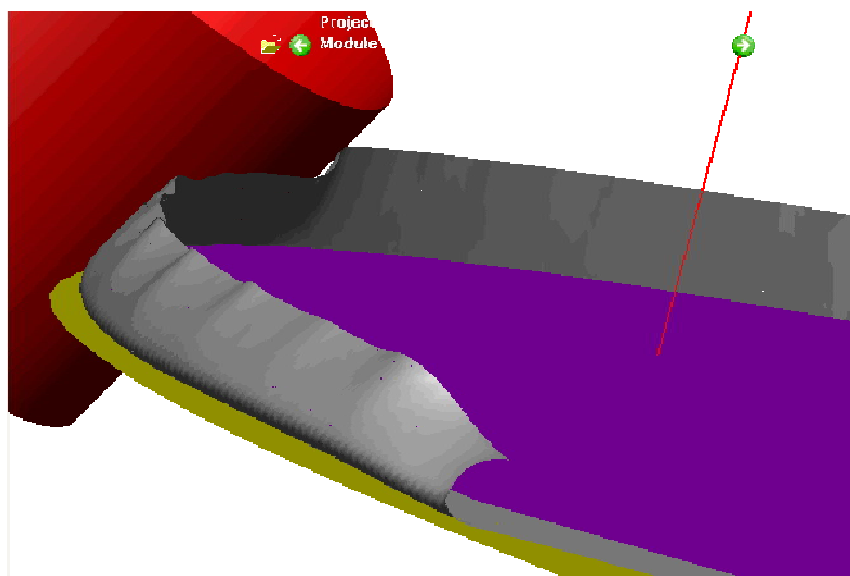


Figure 4. Roll hemming simulation with PAM-STAMP 2G.

Instead of having to rely only on experience to take into account the influence of the many parameters met during the roll hemming operation, the simulation gives you reliable information on flange roll-in and springback, robot kinematics adequacy and surface quality.

The use of only one simulation tool gives the possibility to map results from a forming simulation to the roll hemming models in order to take into account the stamping results in the hemming simulation.

Armed with the simulation results, designers and engineers can take correct decisions on process parameters. The final adjustment of the hemming equipment and process will be minimized and there is less risk of costly re-engineering of tools. Thus, the use of simulation can drastically reduce project times.

5. ASSEMBLY SIMULATION

A car component is manufactured from different parts which are stamped, cast, bent, then welded and connected together to fit the welding assembly requirement.

For complex and large structures, such as in Automotive Industry, standard welding simulation methodologies are not feasible since these methods require significant computation time and disk space.

PAM-ASSEMBLY is a new integrated solution for the simulation of distortion due to Welding Assembly. The main purpose of this tool is to perform distortion engineering with large Welded Assemblies, within a very short time frame. Using PAM-ASSEMBLY, the user is able to compute distortion due to welding and to find the best possible welding sequence and fixture.

In PAM-ASSEMBLY, the Local-Global method is used to simulate the effects of Welding Assembly. It is the most efficient method for large welded designs.

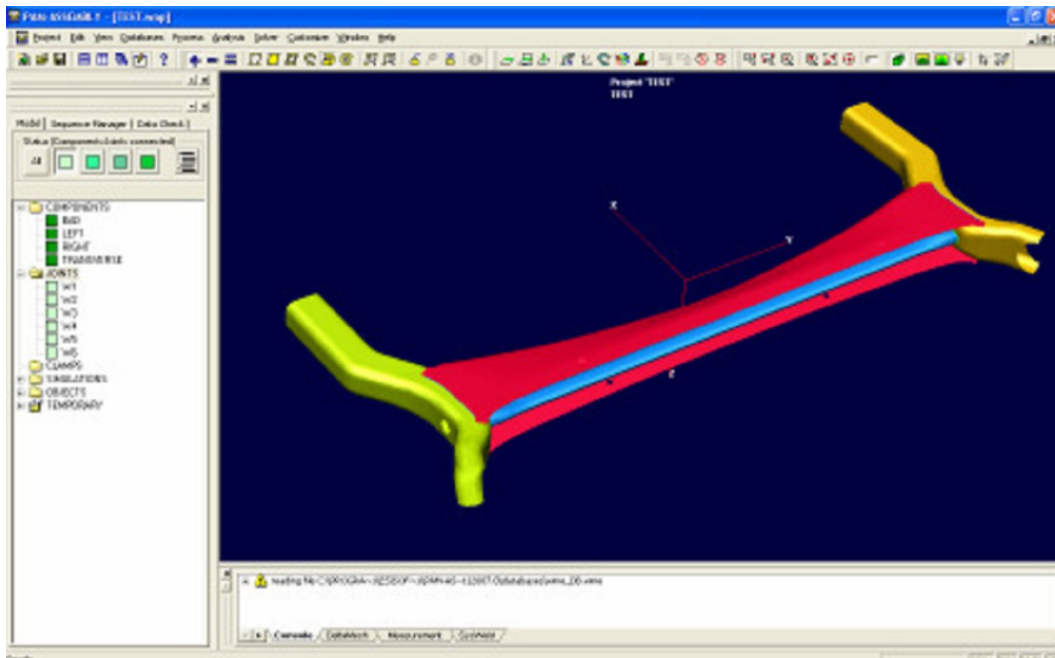


Figure 5. Typical automotive application.

5.1. Basic concept

PAM-ASSEMBLY serves as easy-to-use software to perform Welding Assembly simulations for large structures. The physics of welding is not ignored – it is fully treated in the local models, which are simulated with the SYSWELD™ software. The basic idea behind the Local-Global method implemented in PAM-ASSEMBLY is to provide precision in

Advanced Manufacturing simulation – on one hand without simplification of the welding physics, but on the other very easy to use and very efficient with respect to computation time, even for large assemblies.

In PAM-ASSEMBLY, global components meshed only with shell elements are linked with Welding Macro Elements, which are a new development in the field of Finite Element simulation. Shell meshing is not time consuming and the components are automatically linked via Welding Macro Elements. The results of a transient or steady state welding simulation on a local model are transferred to the Welding Macro Elements in the global model, and the assembly simulation is performed.

Only the meshed components, weld-lines that represent the position and direction of welding seams and the computed results of the local model must be provided.

After having defined fixture and welding sequence, a linear elastic analysis is performed to compute the distortion due to the Welding Assembly process.

Consequently, the user does not need to be familiar with nonlinear Finite Element simulations. All the complex physics is involved only when the local models are generated. This concept allows designers and manufacturing practitioners to simulate quickly distortion, due to the heat effects of welding, without getting involved in non-linear Finite Element issues or numerical methods.

The local models are generated and computed with the Visual Local Model Advisor, a tool for which the Graphic User Interface talks only process related language.

It does not only generate fully automatically meshes from predefined and user-defined cross-sections, it also computes the welding process. Thermal cycles, phase transformations, changes in material status, stresses, plastic strains, thermal strains, yield stress of the newly formed material and all related physics are accounted by the transient welding simulation.

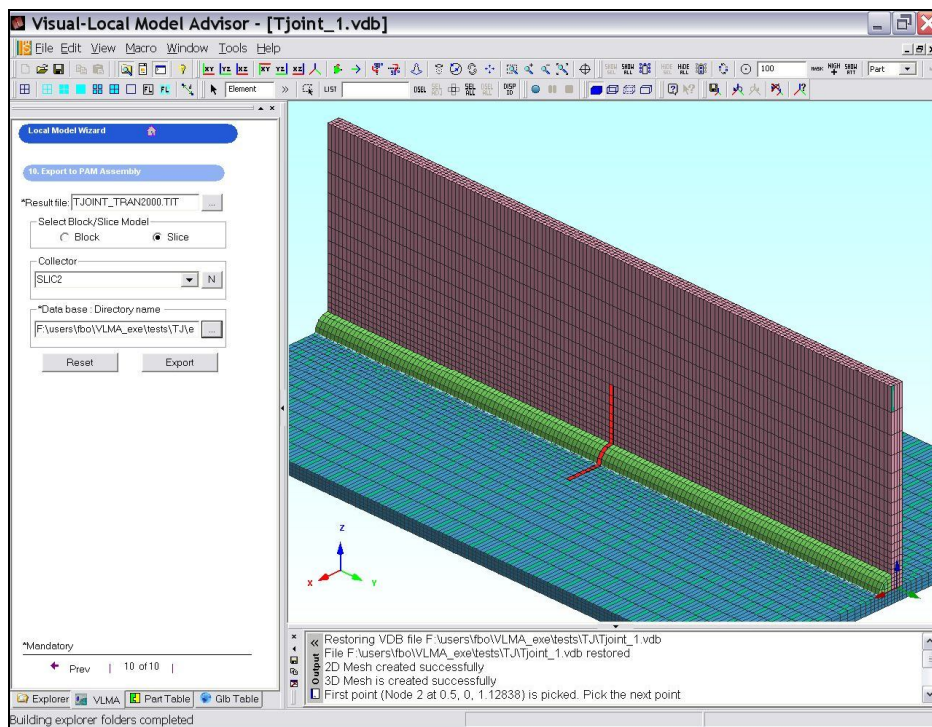


Figure 6. Data transfer to a local model database, which is used in PAM-ASSEMBLY.

The results of the local simulation are then extracted and transferred into the PAM-ASSEMBLY's local model database. The welding process parameters that characterize the welding joints for simulation only consist on an access to the local model database.

5.2. Local-Global method

The idea behind the Local-Global method is that welding is a local modification of stresses and strains, the total effect of which leads to a global state of distortion. In contrast to the classic transient and macro-step methodologies, this welding simulation is performed on a refined local model. Then, the inner forces are transferred from the local model to the global model and an equilibrium simulation is performed to ascertain the global distortion.

Welding processes involve high temperature gradients and metallurgical changes in the microstructure. Consequently, in the heat affected zone and molten zone, the following are generated:

- Plastic strains which cause distortion,
- Residual stresses which can reduce fatigue performance.

In order to reflect the complex physics involved in welding processes, the finite element model has to be meshed with a certain mesh density. For one single pass weld, along the welding trajectory in the molten and heat-affected zone, up to 20.000 solid elements may be needed depending on the process, the configuration of the joint, the material and related gradients. Multiply this figure by the number of welding joints and add the number of elements needed for the surroundings. Therefore, the simulation model of a more complex Welding Assembly would exceed acceptable computational capacities. A solution for simulating such large assemblies is the Local-Global approach, which is based on some physical observations:

- Local phenomenon: High temperature and material non-linearity appear in very small areas around the welding joint. Plastic strains are concentrated around this relatively small-localized zone.

- Global phenomenon: Global distortion of the assembly is due to local plastic strains induced by the welds. The actual behaviour of the global structure itself can be considered elastic.

The simulation of the welding joints (residual plastic strains and stresses) can therefore be separated from the global computation of the assembly (distortion).

Based on the assumption that the distortions of an assembly structure can be obtained by the computation of the elastic response under loads coming from the local plastic effects of each welding joint, a simplified 3-step method is proposed:

- Step 1 - Simulation of the local models

Local models with refined meshes are computed, taking into account all coupled phenomena of welding. The SYSWELD solver provides an automatic solution, covering all complex mathematics and physics. Depending on temperature, phases and proportions of chemical elements, thermal and mechanical properties are computed including phase transformation enthalpy, melting and solidification of material, plasticity and transformation plasticity.

- Step 2 - Transfer of computed results to the global model

In this step, the application of the Welding Macro Element technology (WME) is used, which is a brand new development from ESI Group. It allows maximum computation speed with minimum computer resources, providing a high level of user comfort. This new technology is the key to fully computer-based optimization of welding sequences for large structures.

- Step 3 - Equilibrium simulation (Elastic simulation)

To determine the final distortion, clamping conditions and welding sequences can be modified without the necessity to re-compute the local models.

5.3. Coupling stamping and welding simulations

The assembly simulation is the ideal solution for improving the welding assembly

processes, ensuring better part quality. The coupling of both stamping and welding simulation methodologies enables the user to optimize a complete manufacturing chain.

To couple stamping with welding simulation or welding with stamping simulation (tailored blanks), ESI software has developed links between its products PAM-ASSEMBLY and PAM-STAMP 2G. The coupling of both simulation methodologies enables the user to optimize a complete manufacturing chain.

Welding tailored blanks generates material changes around the welding joints that influence the stamping behavior. Chaining SYSWELD and PAM-STAMP 2G provides the user with key data about changes in material properties like yield stress reduction. The residual stresses from welding are taken into account for the springback simulation.

Welding stamped components made from aluminium and steel alloy is today the mission critical operation for body-in-white and suspension systems. Combining PAM-STAMP 2G and PAM-ASSEMBLY brings an accurate assessment of real blank thickness, change in material, distortions, residual stresses and residual plastic strains.

The coupling is not only available for shell only models, but also for components stamped with shells and assembled with the local-global method.

6. CONCLUSIONS

In this paper, the authors have set out to illustrate some key areas where the application of sound methodologies delivers state of the art predictive simulations in metal forming, offering an insight into the trends and directions currently visible.

The use of metal forming simulation has evolved dramatically over the past decade, and industrial requirements continue to push the boundaries of what is possible, driving the software from tryout validation, through die design, virtual component quality assessments, process optimization, and towards virtual production, and this pace of evolution shows no signs of slowing down.

The chaining of stamping and welding simulation offers the user a new field of play. Rather than stamping components to a nominal CAD shape and subsequently applying geometric adjustments in a fixture in order to compensate for the welding distortion, it appears now possible to stamp to a compensated shape that has been determined beforehand with PAM-ASSEMBLY. The advantages are clear: Forces in the fixture are dramatically reduced, the cost for designing fixtures is also reduced, and the forces that were needed to apply the geometric adjustment in the fixture are no longer retained in the structure after the joining. This means reduced overall residual stress levels which improve the in-service behavior and the fatigue life.

The astonishing benefits, flexibility and power, of the virtual die try-out technique based on finite element simulation are once more demonstrated, but in an extended context. This technique is now coupled with mechanical assembly analysis which is a real breakthrough for 'as built - as tested' applications. 'In service' performance analyses are now based on significantly more realistic models where we take into account the material characteristic changes, and residual stresses inherited from the entire manufacturing chain through stamping and subsequent assembly.

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