The Challenge of the Virtual Manufacturing Chain to Achieve End to End Virtual Prototyping

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Abstract

Virtual manufacturing has become a state of the art tool for the industry. It's a very powerful tool which helps the industry solve many problems in the production. However for the future, there is a clear trend towards end to end virtual manufacturing. This means that the current systems and way of working in the sheet metal forming industry will meet new challenges. This paper shows this trend, and illustrates this by showing a few samples where this trend will have a direct effect on the virtual manufacturing: Integrating the design stage into PLM/CAD systems and linking the simulation directly to theses systems will change the way of working. Simulating also the hemming process after stamping will give valuable information about the whole chain. Hotforming is a typical sample of a new process where several disciplines are involved and the aids of different parts of the virtual prototyping will help solve problems. Finally assembly is an important step in the chain, and will in some cases also influence the way we work in the stamping department. Moving towards end to end virtual prototyping is not done over night, this is a process which will take several years, but it's important to understand the challenges which we will meet the next few years.

1 Introduction

In the past decades different methods of CAE, CAD, CAM etc. systems have become the state of the art method for the manufacturing industry. Many of these systems are purpose build for that special manufacturing process or that special testing procedure. This makes them very powerful for their purpose – and easy and efficient to use. These systems however seem to reach their limitations – the main reason being their traditional strength.

Due to their development in the past, they now have a limited ability to move on to the next step – the end to end virtual prototyping.
Why is there a need for end to end virtual prototyping?
To take a car as a sample: Even if one part has been successfully developed using virtual manufacturing tools, this part will have to perform as expected looking at the whole car. This could be a stamped part, which has to be welded to a cast part. The component group has to be attached to other components. Together they will have to fulfil the crash requirements. But also the requirements towards life expectation, thermal and acoustic insulation etc. have to be fulfilled. The performance of these parts and components towards the required characteristics is normally depending on their manufacturing history. The stamped part will have thickness variations, stresses and strains introduces, modified by the welding which will ultimately change the performance of the component. This is why the whole manufacturing chain has to be taken into account when moving towards the end to end virtual prototyping.
This is not the only sample – the world is full of samples that require components to work together. Many examples can be found also in aerospace, consumer electronics & white goods or for instance in a power plant. Typically new innovative ideas such as wind turbines, hybrid cars or new low-fuel consuming aircraft require full end to end virtual prototyping – as there is limited former knowledge available on the field.

Looking into the virtual manufacturing chain as part of the end to end virtual manufacturing, we are meeting some challenges. This paper will mainly look at the Sheet metal forming, but will also make a brief look into what happens in the assembly after the parts are produced.

2 Sheet metal forming

Within the sheet metal forming (SMF) part of the virtual manufacturing, rapid die face design software has been growing particularly in the die engineering process of Automotive OEMS and TIER suppliers over the past decade. Now there is a new trend moving towards completely integrated die design systems in the host PLM/CAD system. This is a big challenge for the SMF market which has traditionally been dominated by an early feasibility study based on rapid die designs. The main disadvantage of the stand-alone systems used for feasibility checks only is clearly the lack of connected engineering updates. Throughout the design phase for a new product, normally the single parts will undergo several different design changes or adjustments. Every time a change has been made by one of the involved departments, the part needs to be re-worked and remodelled to perform a new feasibility.

With this new trend of moving into the PLM/CAD systems, this rework can be reduced drastically. This new generation of rapid die face design systems utilize the power of the generative modelling and the associatively within the host PLM environment. Another major advantage is that there is no interruption in the data flow, with all die engineering, and design iterations being maintained within the PLM, but still delivering a fast connection to the simulation world for rapid feasibility assessments. This associativity will enable later updates of the part for virtual manufacturing data, due to performance design requirements that require a part design change. This will be a step towards the end to end virtual prototyping

2.1 The influence of die design on the working process

The challenges described in the last paragraph in the SMF market with the new die design trends will have an influence on the working process for the users.

The drawback of the traditional systems has always been that that they are external from the main corporate CAD or PLM system. They have been designed to produce output suitable for simulation, or at very best perhaps for prototype die machining, but they lack the sophistication or precision to allow them to be used in the final CAD-based die design stages. Therefore a significant amount of work has to be put in again in the CAD/PLM environment to redo CAD-based die design.

The new systems have provided a significant business benefit for the users by allowing die addendum concepts to be evaluated for feasibility in forming simulation software at a very early stage in the development process. Later in the design process, the same addendum concepts can be kept – and improved/adjusted if necessary. This reduces significantly the costs for reworking but also avoiding significant hidden costs in CAD modelling and remodelling work after the final validation. See also Fig.1.

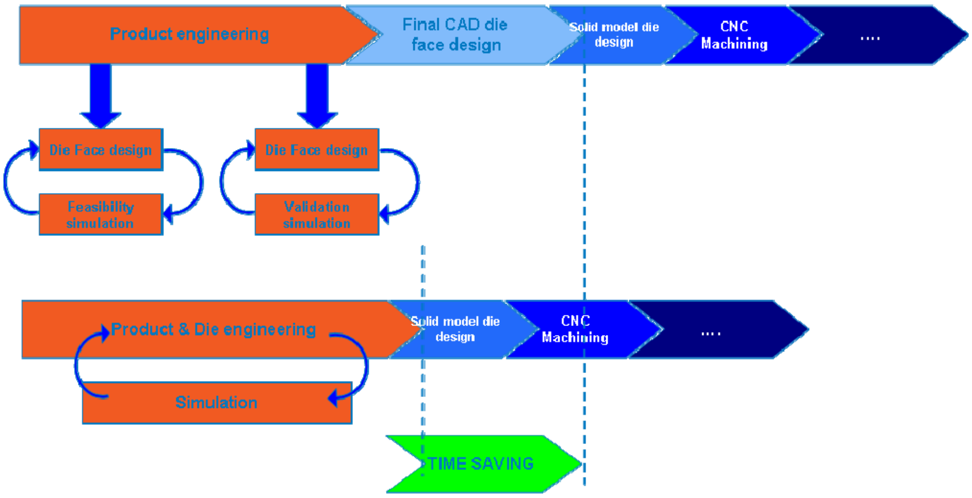

Fig 1. Conventional workflow on top, new proposed workflow based on DIEMAKER for CATIA V5 below – showing clearly the potential time saving.

The benefits of using the new systems mean also that the working process has to be adopted. The user will stay in the same environment throughout the design process. He can at different stages of the design process switch to simulation and then chose which accuracy level he wishes – depending on the stage of the design process. The accuracy can be increased gradually – without need for a break to switch to a different die design / simulation package.

It has already been mentioned that changes happen during the design phase. This is normal, is part of the daily job of the designer. But last minute changes – maybe due to a change in requirements from a different department - are always critical; how to handle these? Go back, build a simulation and calculate again, and iterate until a feasible process setup is found? If ok, build the CAD surfaces etc. This takes too long, and is too risky. With an integrated system, this change is much easier to check and validate.

Another advantage from this system is that the final validation simulation will be performed on the accurate die surfaces that will later be hander over to the tool milling. This makes sure that there is no risk for mistakes or inaccuracy between the two models.

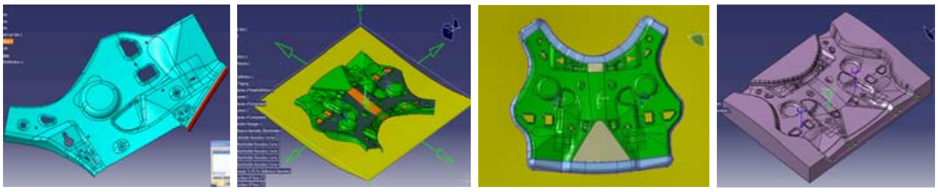

Fig 2. A sample for an integrated die design system; DIEMAKER for CATIA V5; Typical workflow from part over blankholder design to addendum surfaces and finally solid model export.

2.2 Hemming as a part of the chain

Traditionally the stamping department has worried about the stamping issues, and been focused to solve, not worrying too much about what comes next. But the part needs to be assembled or attached to other parts in order to function as a part of the finished product. One way to attach two parts to each other is the hemming process, where one blank is folded over the other to make up a fixed joint.

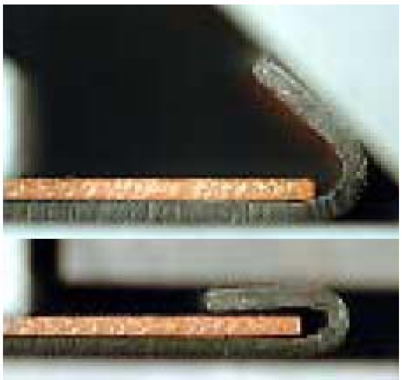

Fig. 3. The hemming process

The hemming process itself is interesting to look into with the potential problems that can arise – e.g. rupture on the outside. Apart from that, looking at the hemming process as part of the chain makes sense. If the joint after the hemming is not tight enough, parts might fall apart during a crash, or they might cause noises – influencing the quality of a product.

Another factor is the draw-in of the outer blank during the hemming process. As normally the size and shape of the end part is the required one, the size & shape after the hemming needs to be compared to the required. If this doesn’t match, it might be necessary to go back and change the stamping process to makes sure enough material is available for the hemming process.

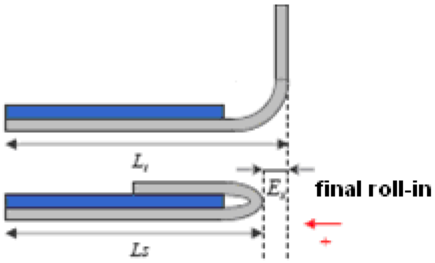

Fig. 4. Final roll-in after the hemming process

So to simulate the hemming after the stamping – before going into production – will reduce the risk of having to go back to modify the stamping process during prototyping, and hence means that this is another step in the chain for the full end to end virtual prototyping.

2.3 Hotforming as a sample where the whole picture is crucial

Another sample is hotforming. This is growing rapidly, and is a fascinating manufacturing technique, where the good formability of the warm blank is combined with exceptional strength of the end part due to the quenching in the tools. No traditional available material that is formable is even close to the strength of the hotformed steel. This makes it a natural choice for the crash relevant parts in the car. Today all major OEMs work with hotformed parts in the cars as crash re-enforcements. It allows building even small sized cars with an outstanding crash performance – enabling the traditionally weaker group A cars also to get the 5 stars in the EURO-NCAP crash tests (e.g. Fiat 500). This means that looking only on the formability of the part during stamping doesn't really make sense. The whole chain has to be kept in mind – this from early design stage on. To get the properties of the end part right is crucial to achieve the crash performance. This means that the crash engineers have to rely on the stamping department to manufacture the parts with the right properties.

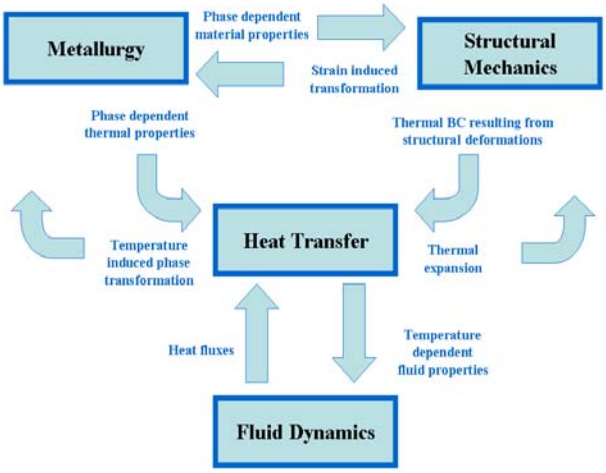

Fig 5. Showing the complexity of the hotforming process interactions.

Hotforming itself is already a manufacturing technique where different fields will play together to make it work or not, see Fig 5. The stamping department has to build knowledge now also in metallurgy, heat transfer, cooling and fluid dynamics – areas where normally several specialists are involved.

So to summarize, with this new process, the stamp engineer is suddenly confronted with several new areas where he has to have a high level of knowledge to get the process right. Even for the most talented engineers, it will be to ask for too much to become an expert in all these fields. This is typical area where the virtual manufacturing can play an important role in getting the new processes running. The part manufacturing with all its different aspects can be tested virtually before the expensive hotforming process is started. Also the part performance in the final crash can be tested virtually. Again a step towards the end to end virtual manufacturing – even if the challenge to simulate all the different aspects still remains.

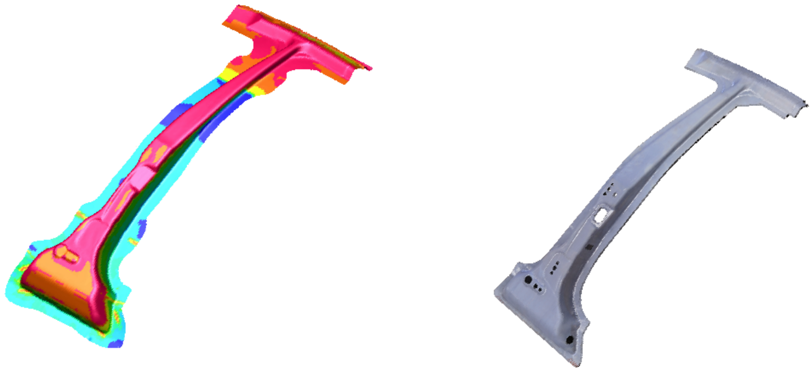

Fig 6. Simulated and real manufactured hotformed B-pillar. Courtesy of AP&T Group.

3 Assembly – Welding

According to the industry research organization Grant Thornton LLC, the Detroit Three will shrink their current 40 platforms (2009 number) to 29 by 2014, less than four years away. This trend can be seen all over the World. This means for the 1st tier suppliers that Right First Time at permanently reduced cost is becoming a survival necessity.

Looking at automotive assemblies, the ultimate goal is to get a stress minimized body assembly within tolerances at the minimum cost, fulfilling the specs. The manufacturing shop floor needs to keep tolerances that have been designed by planning. The more design and planning is able to deliver input to manufacturing that needs no further correction by manufacturing with respect to keeping tolerances, the higher are the chances to be the first choice for a supplier in the market.

The goal of stress minimization has serious reasons, but is contrary to keeping tight tolerances – the more the components are clamped for joining, the more residual stresses are in the structure after release. Residual stresses can cause change of shape in case of painting or body modifications when the assembled body is modified to fit to engine and power train variants. Residual stresses have a negative impact on fatigue.

Joining to assembly tolerances with minimum clamping and thus minimum residual stresses is best done with distortion compensated components. However, the compensation proposal for an assembly with many components is fairly complicated.

To solve the problem is thus not straight forward and causes a lot of cost. The simulation of the complete manufacturing chain is the most powerful tool to minimize this cost. Engineers work in three steps to achieve this goal.

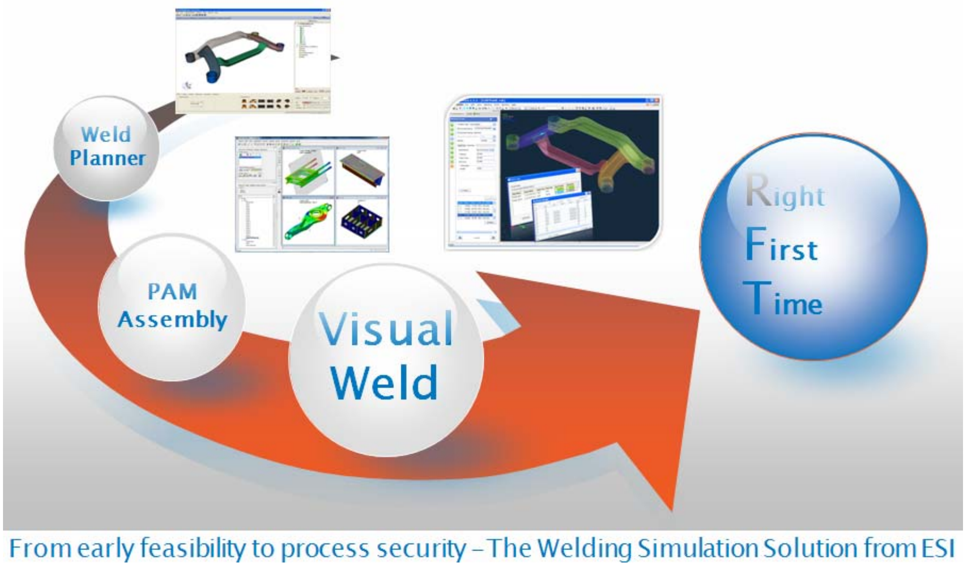

Fig 7: Welding simulation solution

First, the welding assembly is optimized with respect to the goals, without compensation. The early feasibility part of this solution has been developed by INPRO and ESI, with the direct support of Daimler, Volkswagen, and ThyssenKrupp. The software for the early feasibility part of the welding assembly evaluation is named Weld Planner. It is a part of the Welding Simulation Solution. It has been designed to find the major contributors to distortion in a welded assembly at minimum cost. It is applicable for all hot and cold joining methods. How do engineers work with the existing solution? First, a quick evaluation of the assembly is done. With an intelligent strategy, it takes only minutes to indentify the joints that cause the majority of the distortion. Once the major contributors are identified, clamping conditions and weld sequences can be optimized to fit distortion within tolerances. This takes again only minutes for each variant. The optimization of the clamping tools without simulation is a difficult task – the more clamped, the more stresses will be conserved in the structure, which is completely the contrary of the goal. The less clamped, the more distortion will result, however, one needs to keep the tolerances. The Weld Planner enables to find quickly the best compromise, in less than a day. At the end of the evaluation, a complete sequence can be performed to confirm the global picture.

Once the distortion due to welding is minimized, the tool compensation for each component can be proposed in a second step. It is today possible to chain the Welding Assembly with sheet metal forming simulations carried out in PAMSTAMP 2G. This allows including the physics of material in component manufacturing in an assembly simulation, in an acceptable time frame.

At the end, the complete design is validated with a transient simulation of the complete joining process, using Visual Weld from ESI.

4 Casting

In complex assemblies in general a number of components are produced by casting processes. While in the past the demand on casting modelling was generally the control of the casting process itself to obtain sufficient part quality the request is increasing to integrate the process simulation into a value chain of virtual prototyping.

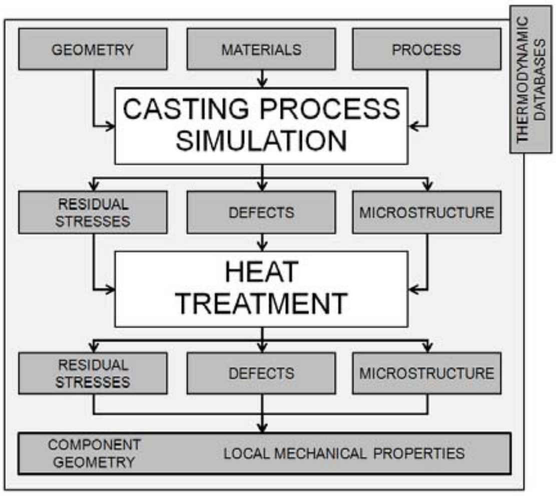

Fig. 8: Casting and heat treatment modelling scheme.

Task of the modelling is to predict local mechanical properties and the final shape of the component based on geometry, material properties and specific casting process parameters (Fig. 8). Often heat treatment is also part of the process and needs therefore to be taken into account to predict the behaviour of the final part under service conditions.

Both casting and heat treatment modelling are supported by thermodynamic material databases.

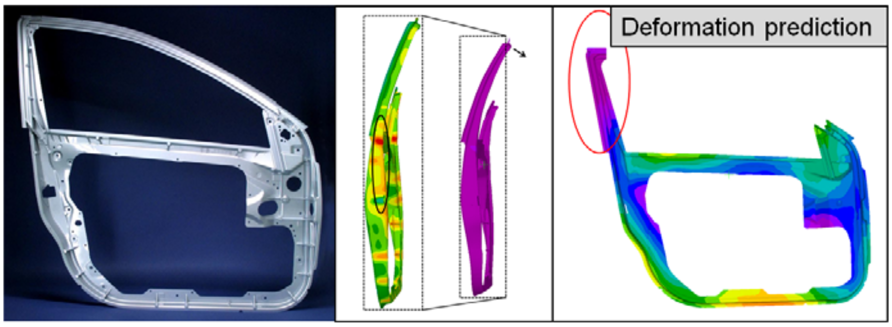

Fig 9: Deformation prediction of a door from Mercedes Benz (Courtesy of +GF+)

Fig.9 shows a typical example for a deformation prediction /3/ in the process of High Pressure Die Casting (HPDC). Due to a wrong process temperature control (hot spots in the middle of the part, see Fig.8 centre) the upper part of the door was out of the defined tolerances (see Fig. 8 right side) after cooling to room temperature. Similar structural parts in automotive are often also assembled by welding after casting. A combined modelling solution including casting and welding assembly is therefore of high value for the industry.

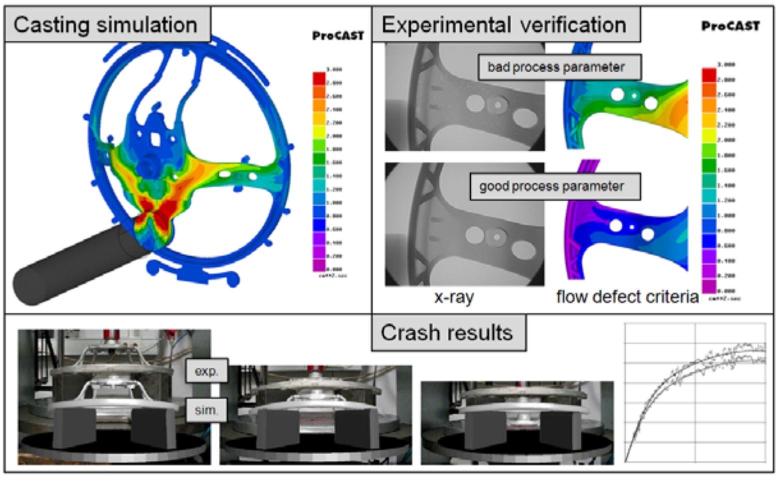

Fig 10: Chaining of casting and crash simulation (Courtesy of Takata Petri)

While crash simulation is often based on the assumption of homogeneous material properties, it is known, that these properties are largely influences by casting defects. Fig.10 shows an example /4/, where the material is degraded by defects originated from unfavourable flow pattern in the casting chamber (air bubbles, inclusions). Using the defect distribution from the casting simulation to define an inhomogeneous distribution of mechanical properties over the part leads to realistic crash simulation results, which was confirmed by experiments (Fig. 10 bottom).

5 End to End Virtual Prototyping – an outlook

“The future is green” is a very hot topic at the moment all over the world. The pressure on all manufacturing industry is huge – to use lighter and more environmental friendly materials, new manufacturing techniques, new designs etc. meaning going into today unknown areas. All these “new” – and very limited experience on “how to”. The traditional prototyping, testing & evaluation with repeated loops until the feasible design is found not only takes too much time and costs too much money. Using end to end virtual prototyping is a way to test all these new ideas, process, materials, methods in way that hardly any resources are used. Running a computer, letting it to do the testing is a far more environmental friendly way to do the prototyping than to build numerous physical models.

Switching from real prototyping to the full end to end virtual prototyping is however not a small job done over night. All the involved departments will have to work together to make up the chain. Virtual manufacturing is part of that chain, and step by step will have to adopt to deliver its contribution.

We have seen samples here of some steps how this can be done with changing the die design process, integrating hemming simulation into the chain, and casting and welding. This is a process that has started, and will continue for several years. End to end virtual prototyping will be the future of how products are developed and built. The first steps have been done.

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