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This issue contains three blog posts.

Can You Decrease Blank Sizes to Save Money Without Consequences? (Part 1 of 2)

Introduction

In the sheet metal forming industry, it is a common practice to decrease blank sizes as much as possible, with the goal of saving material and therefore money.

This step is usually performed at the end of the tool tryout phase or at the beginning of part production, if it hasn't already been completed during the engineering phase.

It's immediately apparent that this optimization allows companies to save millions per year, but can we say with certainty that this is always the case? Are there any resulting consequences for the part production that result from such minimization that have been overlooked?

Surely, there will be ramifications of some sort, but the question is: are they acceptable? In other words, are we certain we are actually saving money overall?

It's important to examine the real knock-on effects.

This is exactly the evaluation that the engineering department of an automotive part maker wanted to perform: a deep analysis of the consequences of reducing the blank size on the stability of the production.

So with this end in mind, where should we begin the investigation? What parameters will we need to include and what result variables should we check to determine the blank optimization effectiveness?

We have already mentioned that the blank optimization is done in tool tryout, where the material of the blank has precise characteristics (thickness, yield stress, etc.). The question to ask ourselves is: does this scenario 100% reflect the production scenario? And the answer is no. Material for production, even possessing characteristics within a certain range, will likely be different because they come from another coil (check the value's distribution of the different characteristics) with differing amounts of lubrication, strokes per minute, press type, and blank position.

In order to account for these differences, **robustness** checks on different blank sizes are required to simulate the expected outcome of a part production process in advance. This will ensure the results are suitable when considering process parameter variation. In other words, robustness checks account for the noise of variables that cannot be controlled during production. In our example, we consider:

- Lubrication

- Binder force
- Sheet thickness
- Average material R-value (material anisotropy)
- Material yield stress and tensile strength (interdependent through a correlation factor)

Example: Door Inner

As an example, we can consider the complete process including springback of manufacturing a door inner (two parts in one tool). The evaluation criteria involves checking the following parameters:

1. **Price:** The lowest possible price of the nested blank
2. **Draw-in:** After D-30 drawing operation, the blank edge should not pass the inner drawbead (minimum 4mm distance from the center line of the bead – yellow line in Figure 1)
3. **Defect rate for splits:** Estimate defect rate related to splits during production at the end of D-30 by checking the max failure result with max value set to 1; current nominal result fulfils the requirements being equal to 0.946 at maximum
4. **Springback stability:** ±0.5mm springback tolerances of the final part

Of course, additional quality criteria could be taken into account, but we will keep the concept as simple as possible for this blog article. For the blank modification itself, the draw-in of the nominal blank on all three sides (we consider symmetry) is already very close to the inner drawbeads (see Figure 1). The width of the blank (1300mm) must be constant, as a modification would violate criteria #2 of the above list. Nevertheless, the two corners above and below offer potential to minimize the blank size in the x-direction, as shown in Figure 1. So in our simulation, both points will be defined as interdependent design variables (i.e., can be controlled) in the x-direction with a variation range of ±30mm for the robustness setup. This allows the users to evaluate the robustness of different blank sizes simultaneously in one AutoForm-Sigma analysis.

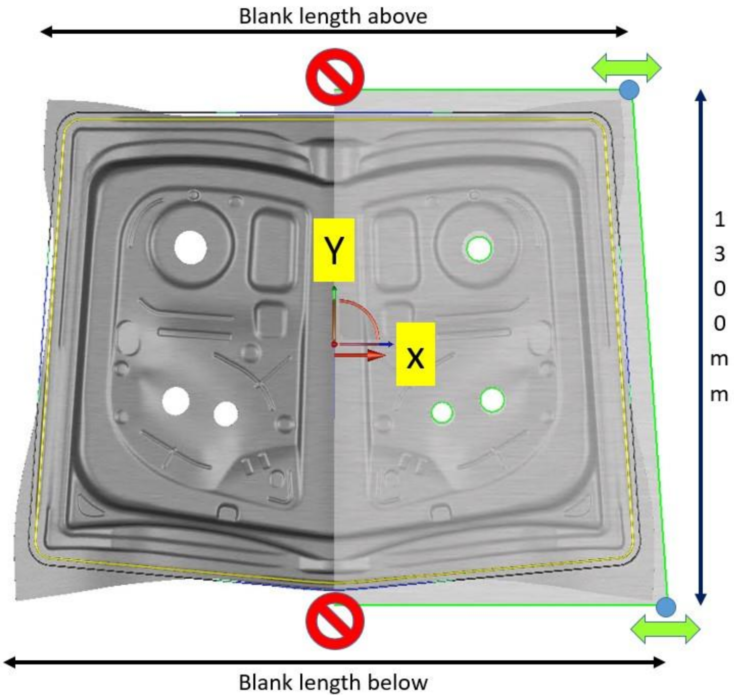


Figure 1: Green curve = nominal blank; formed sheet = draw-in of the nominal blank; yellow curve = inner drawbead

Results

Before deciding on the optimum blank size, we first examine the robustness of the engineering intent.

Nominal blank

- Blank size: 1500mm length above & 1680mm length below

The result of the robustness analysis with the **nominal blank** leads to the following output:

1. **Price**: 9.27€ (Figure 2)
2. **Draw-in** at end of D-30: fulfilled (Figure 1)
3. **Defect rate** for splits at the end of D-30: > 10.7% (variation of max failure based on production parameter variation: 0.727 – 1.2). Note: The single simulation with nominal blank fulfilled this limit; *nevertheless, the robustness check shows that there is a sensitive area for noise variables that leads to this defect rate* (Figure 3). This means that in tool tryout or production, we can experience splits if the material or the other noise parameters differ from what was used in the single simulation (the engineering intent).
4. **Springback stability** of the final part: very stable springback behavior except for a small local orange area (unreliable) with a defect rate of > 0.007% (Figure 4)

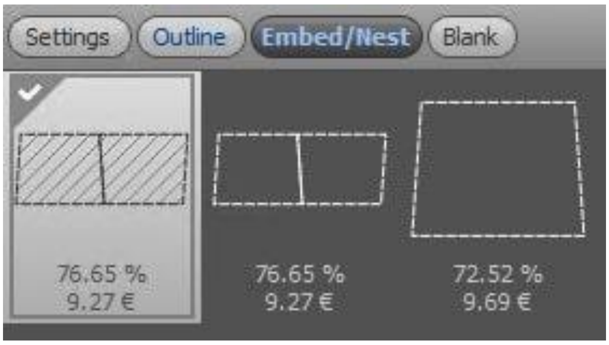


Figure 2: Lowest price based on optimal nested blanks for the nominal blank

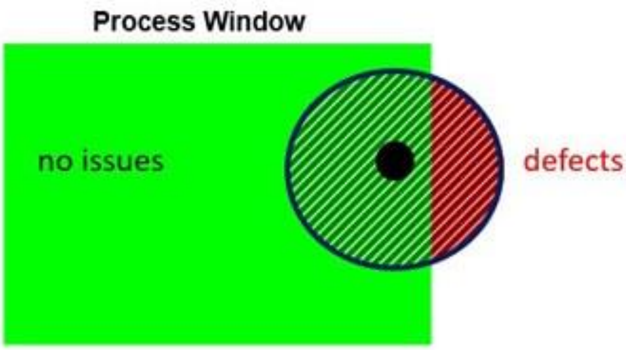


Figure 3: Single simulation result vs. robustness check result
– the importance of process window detection

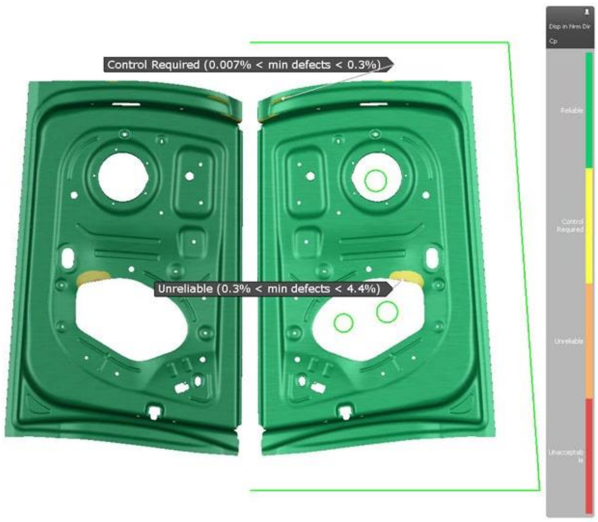


Figure 4: Springback stability (CP-value) for the nominal blank

Optimized blank

Once the calculation of the possible input-output combinations was over, we were able to compare the results and look for the smaller blank size that ensured compliance with the constraints previously listed:

- New blank size: **1525mm** length above & **1633mm** length below

The results of the robustness analysis generated by the **optimized blank** are as follows:

1. **Price:** 9.21€ (Figure 5) à savings of 0.06€ per blank compared to nominal blank
2. **Draw-in** limitations at end of D-30: fulfilled
3. **Defect rate** for splits at the end of D-30: > 3.1% (variation of max failure during production parameter variation: 0.66 – 1.118)
4. **Springback stability** of the final part: still very stable springback behavior, except a small local orange area (unreliable) with a defect rate of > 0.3% (Figure 6)

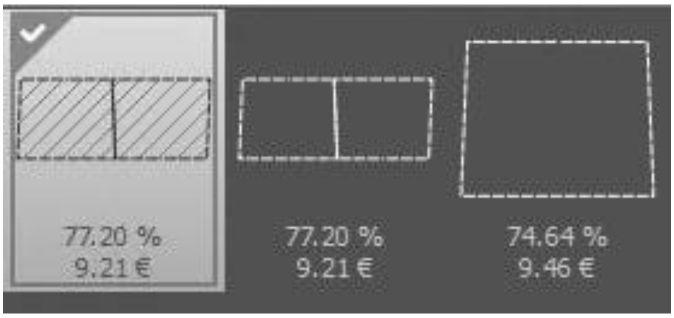


Figure 5: Lowest price based on optimal nested blanks for the optimized blank

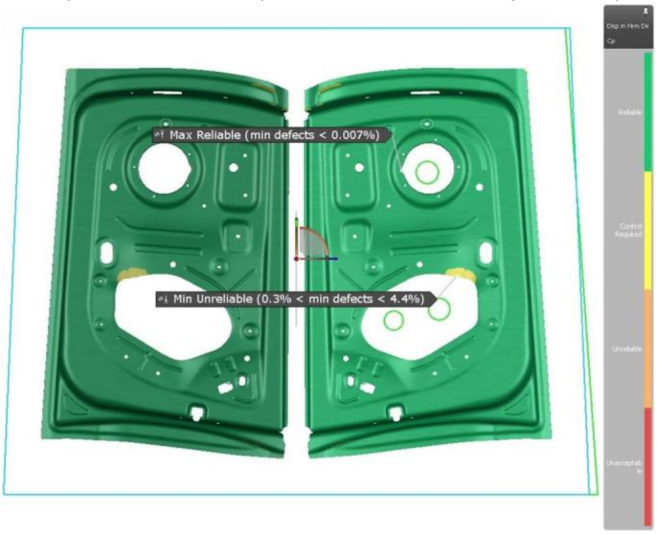


Figure 6: Springback stability (CP-value) for the optimized blank
(=blue curve; nominal blank = green curve)

Conclusions

As shown in Table 1, it is indeed possible to decrease blank size to save money without negatively impacting production (same stability). The optimized blank would actually lead to a much lower defect rate of splits (lower reject rate in production à additional saving) by achieving comparably stable springback behavior. In addition, we save six Euro-cents per blank compared to the initial engineering intent blank size! So, is it worth taking this approach in the end? It is, without a doubt in this case.

	Nominal blank	Optimized blank
Blank size (length above & length below)	1500mm length above & 1680mm length below	1525mm length above & 1633mm length below
Price	9.27€	9.21€
Draw-In at the end of D-30	Fulfilled	Fulfilled
Defect rate for splits at the end of D-30	> 10.7%	> 3.1%
Springback stability on final part	> 0.7%	> 0.3%

Table 1: Summary of the results for both blanks and criteria

To more accurately estimate the total savings, we must refer to the part cost on a certain production volume. Assuming a production volume of 2 million (car life cycle), as shown in Figure 7, we save 0.49€ per part. Over the entire life cycle, this translates to a savings of 980,000€ – not a bad return on investment for a few hours of simulation during the engineering phase!

For completeness, we should also mention that a more stable process reduces the number of interruptions during production to adjust process parameters as the production evolves. We will further discuss this aspect in a subsequent blog, as die line downtimes represent a very relevant production cost.

Figure 7: Total cost per piece – normal blank versus improved blank

Now we should ask the question: can we always expect that decreasing the blank size to save money will not have negative consequences for any part of the process? Of course not! We have to comprehensively evaluate every project individually. However, this kind of analysis will help designers to make the most beneficial decisions and potentially avoid negative surprises in tool tryout or production.

A sample result of a non-comprehensive but deceptive analysis will be discussed in the second part of this blog article on FormingWorld.com. Stay tuned!

By Michael Stippak & Martin Milch, AutoForm

Prabha Industries India: Sidewall Curl Control for HSS 980 Material Sill Part

The story we are about to share with you illustrates how crucial it is to take into account the springback phenomenon, particularly when working with a material that has novel characteristics. When you're trying to find the best countermeasure (process plan and parameters, tool shape, etc.) in the sheet metal forming industry, you absolutely cannot neglect the main principles or proceed without the right software that will help you get to the root of the issue.

Prabha Industries contacted AutoForm-India to find out the ideas to successfully control sidewall curl phenomenon for a sill part made from 980DP steel.

Ravikumar, project in charge of Prabha Industries got in touch with us during the engineering phase where the tools were not built yet. They made several iterations considering four processes finalized as per initial study. Sidewall curl was an issue that did not solve in spite of several iterations.

The client approached us for a joint study to eliminate spring back and sidewall curl and to avoid multiple recuts of the die in tryout phase.

For mild steels, a single crash forming operation is usually enough to form the part shown in Fig 1. However, this may not be the best approach for dual phase steels. For this reason, we will outline some alternate methods for dealing with AHSS materials.

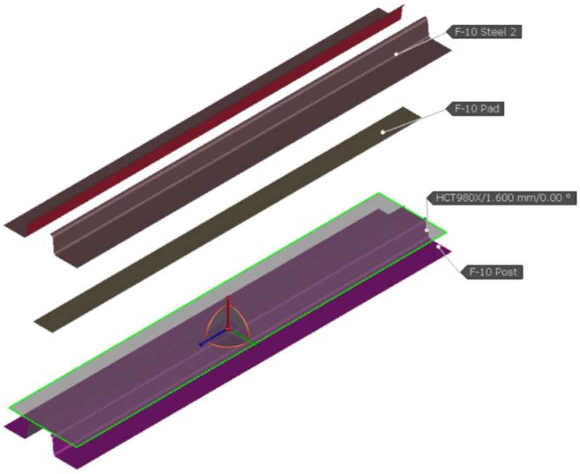


Fig. 1: Tool set-up for one-step forming operation

As seen in Fig. 1, the stamping process starts of as a wipe and continues on full cam form. This process resulted in side wall curl as shown below (see Fig. 2); essentially, a conventional method that was causing problems.

Fig. 2: The top left shows the occurrence of side-wall curling

Trying to counteract side wall curl with spring back compensation is not easy and the probability of success is quite low, making compensation practically impossible.

"With the scope of keeping the process as close as possible to the customer's engineering intent, we tried several methods to control this curvature on the wall," said Mayank, Technical Account Manager at AutoForm, India. "But, as the joint study with our customer revealed, alternative strategies would be required to deal with AHSS. Firstly, we ran a root cause analysis, to understand the reason for the curling. We analyzed the differences in stresses in the outermost and innermost layers of the sheet in the wall area, whilst it underwent bending during the forming operation."

The study showed that the stress on the outer layer was positive, while the inner layer stress was extremely negative. This difference generally translates to instability, and it resulted in the curling behavior (see Fig. 3).

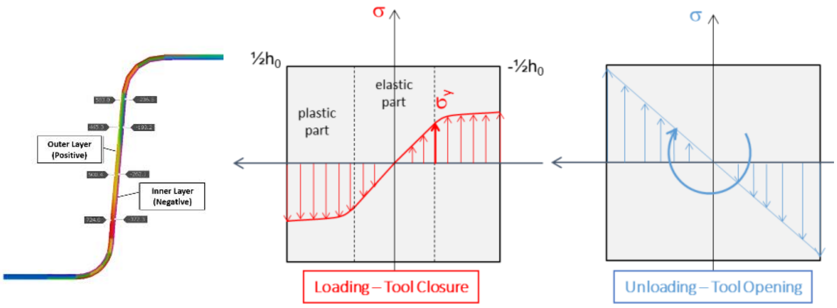
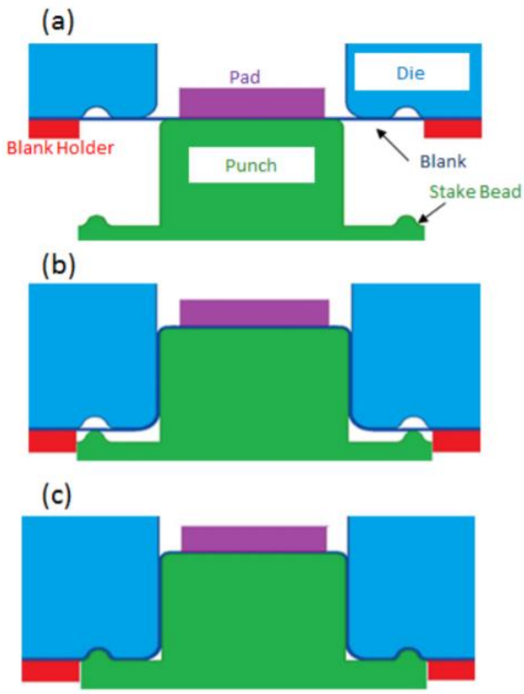


Fig. 3: Difference of stress between the outer and inner layer.

The residual stress along the thickness of the wall was the sum of loading and unloading stresses. The result was the presence of compressed and stretched areas, which caused the instability.

Rather than searching for a compensation strategy, we focused on minimizing the differences in stress occurring along the thickness of the side wall itself. Only after this was achieved did we move on to compensating the tools.



We proceeded with an approach that we have actually been teaching for years in our training sessions: turning "pure bending" stress distribution into "superposed" stress distribution (see Fig. 6). To obtain this effect, the wall cannot undergo pure bending, but it must be stretched.

To accomplish this goal, we evaluated the following two strategies in our study:

Strategy 1: Post-Stretch with Stake Beads in Punch

This is one of the oldest methods for stretching the material close to the end of press stroke. This strategy would entail adding stake beads to the punch. This would balance out the stress differences of the outer and inner layers of the material, in turn reducing both the spring back and the side wall curling.

Fig. 4 (above right) shows the forming process at three different time steps: (a) binder closure, (b) hat shape reached (still a few millimeters from the bottom), and (c) tool closure: beads are formed and the wall area is additionally stretched.

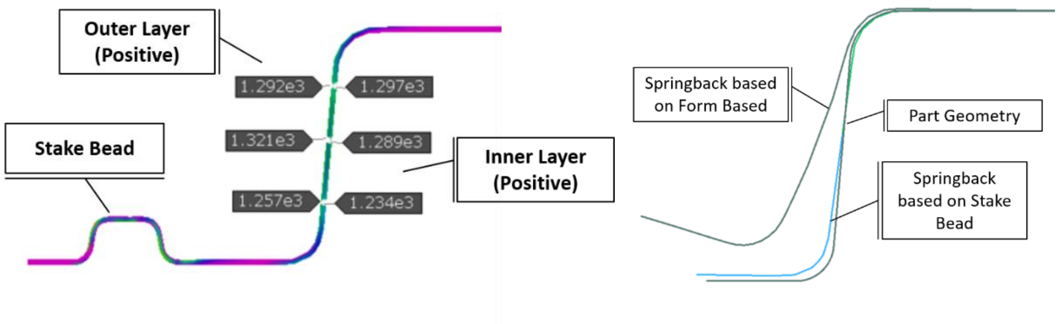


Fig. 5: Springback results applying stake bead in punch

We set up the process for the first strategy and ran the simulation. The results are shown in Fig. 5.

As you can see, both stresses (inner and outer layers) are now positive (left picture), giving the sheet greater stability. This results in a smaller magnitude of the springback effect (right picture).

To better understand what this means, we can refer to Fig. 6. If we look at the resultant stress curve, there is no longer a momentum effect due to the two different stresses, which would lead to a kind of “rotation” of the element. Instead, we now have a more uniform stress, resulting in a “shrink effect” along its length. The “unbending-rotation” effect that caused the curl has disappeared.

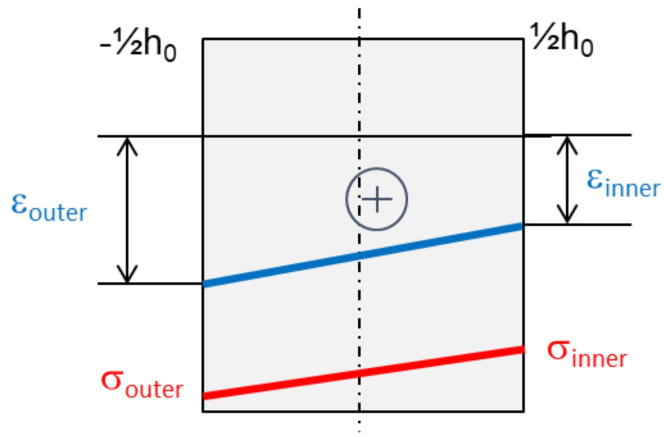


Fig. 6: Stress and strain distribution after post-stretching

This strategy can work, but also has downsides.

The first disadvantage is that the part requires a larger blank in order to accommodate the stake beads, which means increased material cost (lower material utilization factor). The other issue is that it requires a very high press-tonnage to achieve the additional stretch required to form the part. Although this solution worked well, we wanted to evaluate the second strategy as well for cost benefit analysis before finalizing the desired strategy.

Strategy 2: Multiple Forming Operations

For the second strategy, we decided to add another forming operation rather than changing the tool shape (Fig. 7).

The part was initially bent upward and then downward to form the final shape. While springback was still high when using this method (when compared with the stake bead method), the problem of the wall curling was entirely eliminated, resulting in a pure angular springback. This can easily be corrected by adding a compensation to form and an additional CAM-Restrike operation.

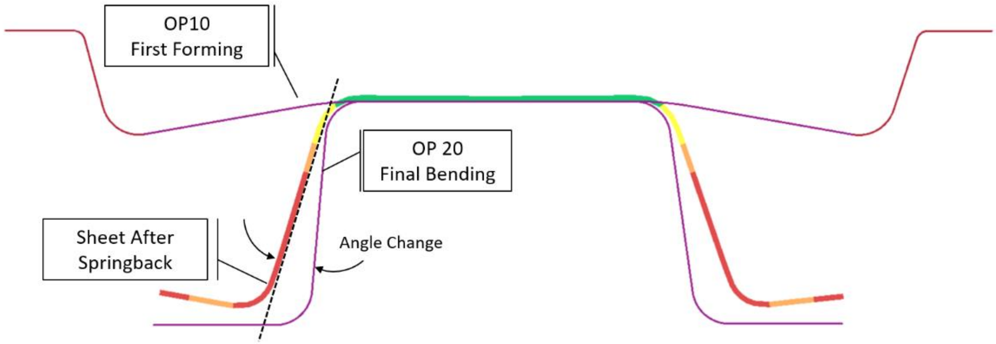


Fig. 7: Form based two-step forming, resulting in pure angular springback without any curl on the wall.

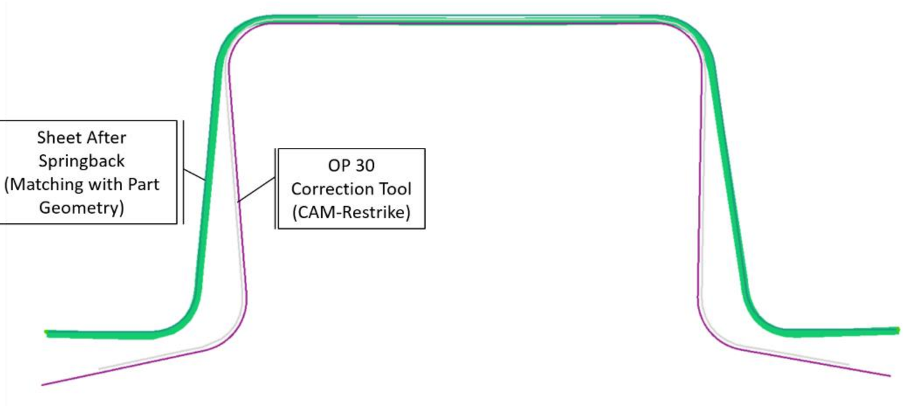


Fig. 8: Final springback after compensation using CAM-Restrike tool

In the end, the client chose to adopt the second method, using multi-step forming operation. Despite the increased cost due to additional operation, it improved stability of the process (the stresses are under far greater control, which results in a lower scrap rate during production) and also considering the large number of parts being produced, this solution proves to be far cheaper in the long run.

The outcome of the joint study was shared with the end customer, who approved additional die operation for process robustness. Dies were manufactured as per new operation lineup. The parts came out during trials did not had side wall curling and only angular spring back was observed for which dies were further compensated during actual trials.

In addition, as we at AutoForm always recommend, the process robustness must be checked before delivering the tool design for manufacturing. With this analysis, we want to make sure that issues due to process variability do not arise in tryout or (more importantly) in production, causing press line downtime. These problems could skyrocket costs making all engineering efforts in vain.

Raghuram Shenoy, engineering head at Prabha Industries said, “This exercise shows that before we start working on compensation, we must have a robust process, especially in the case Advance High Strength Steels. This could be a more complex die process which would be cost effective in longer run. Otherwise, it could mean a more robust product design that lends itself to simpler die process. “

Thanks to Prabha Industries for sharing this interesting case study.

Bringing Material Data to Life: Making Material Cards Meaningful Along the Stamping Process Chain

Hope for the Best – But Prepare for the Worst

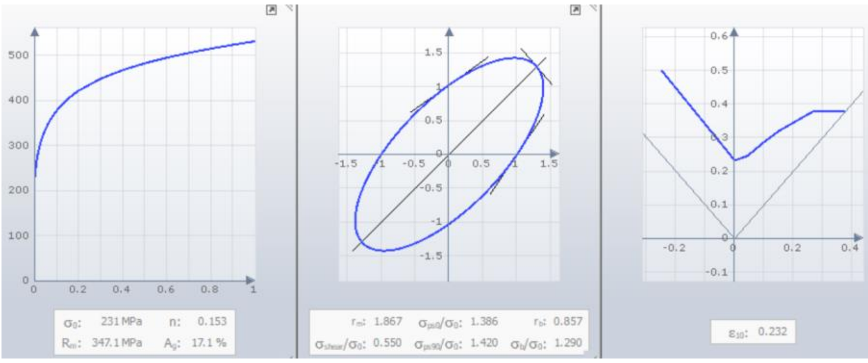
Within the sheet metal stamping industry, the goal of a process engineer is to define the process and geometric parameters based on which tools are built to produce a certain number of car body parts (i.e. 200,000 parts for a certain car volume). All of this must be within the required dimensional tolerances and meet the desired aesthetic quality. To achieve this goal in the virtual world – where changes are easy, fast and inexpensive – stamping process simulation software is used to define and validate all relevant process parameters. The tool manufacturing team and production line will then have to carry out the rest of the process in the “real” world.

Shifting from the virtual to the real world, simulating conditions that can be matched in reality is crucial for the efficiency of the entire process. However, can all parameters always be duplicated in reality – if so, within what tolerance? And finally, what does this mean for cost-time efficiency of the entire process?

In order to get to the bottom of these issues, we’re going to address one set of essential input parameters that significantly affect the reliability of the simulation results: material characteristics.

How close are the simulated material properties to the *real* material used in tool tryout and production? At the other end of the spectrum, what are the chances that the real material properties used in tryout will match the properties used in simulation? How would I even know whether I have a match? After all, the tests required to reach a meaningful mathematical description of the plastic deformation behavior of any sheet metal are totally different from the multiple stretching directions occurring in reality.

The figure below shows just some of the parameters needed to describe the behavior of the material and evaluation criteria (hardening curve, yield surface, forming limit diagram with FLC, etc.).



During the feasibility analysis of the part early on in the process, the grade of the material is defined by the carmaker. Further, the properties available to the process engineers are limited to what is *generically* specified, either by the OEM or by international standards (EN, DIN, VDA, etc.).

For instance, let’s assume the designed steel grade for the part is CR210xxx (Cold Rolled Steel, min. yield stress = 210 Mpa). Of course, we need to define far more parameters for the material behavior during stamping operations than simply yield (**$R_{p0.2}$**) and ultimate strength (**R_m**). But, for the sake of the example, we will focus on just these two parameters – and we’ll quickly realize how complicated the scenario becomes, even while neglecting all of the other necessary parameters!

In addition to this basic information, material makers provide a range of values for these characteristics in order to allow for typical scatter of real-life production conditions. Let’s assume we are dealing with the data shown in the table below.

Material grade	$R_{p0.2}$ [MPa]	R_m [MPa]
CR210	210-270	340-420

Which values should we input for a feasibility study? One might suggest: *let's identify the worst-case scenario and go with that*! Then the question becomes, what is the **worst-case scenario**?

Keep this concept in mind, as we'll return to it later on.

The material supplier may be as yet undetermined during the *advanced feasibility* and *full stamping process validation* phases, particularly when the part producer is still shopping around for the best offers. Uncertainty abounds even while the engineering study is progressing and tools are being designed. The process has been digitally designed and validated, despite this looming uncertainty. Thus, the sooner the supplier is found, the better! However, supplier identification is a parallel process that often has nothing to do with the engineering study; it's in the hands of the purchasing department.

Fortunately, the tools have not yet been manufactured by the time supplier negotiations are complete. The process engineer may still find a set of parameters to generate green results and deliver them downstream. If the tools are about to be milled, though, the game would be over for engineering since the data would simply arrive too late to be considered.

Now, let's assume the information comes in before the tool geometries have been released. The process engineer is now considering not only material characteristics, but also statistical distributions of the material parameters (i.e. histograms) - provided by the material supplier. This data may appear as in the figure below.

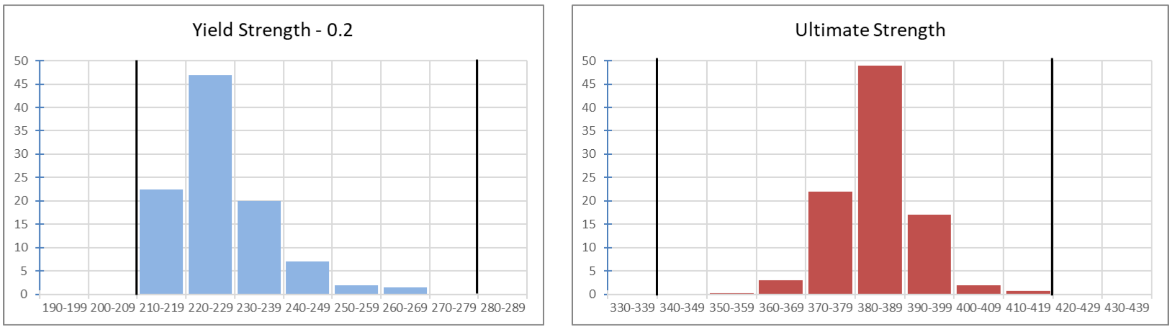


Figure 1 - Typical statistical distributions (histograms) of material properties

In this case, if the process engineer sticks to the *mean rule* for the simulation set-up (this information is not yet available and a guess has to be made), using the mean value of the two ranges (yield $R_{p0.2}$=240MPa and ultimate R_m=375MPa) – the chances that the yield strength used in simulation will match that of the actual material received by the part producer at the plant is roughly 3.5% (7% x 50%)!

On the other hand, if the simulated values used were the minimum of the respective range ($R_{p0.2}$=210MPa and R_m=340MPa), the probability that the real material in production matches the simulated data is zero!

Fortunately, this doesn't necessarily mean that the final part is 100% scrap – but it *does* mean that what will happen in reality has not been simulated at all.

Returning to our earlier consideration: what would be the worst-case scenario parameters? Truthfully, they all could have been good or bad. Before knowing the statistical distribution from the identified material supplier, the engineer can only make guesses.

Prior to production, tools are *tested* and fine-tuned during the tool tryout process. This is an iterative process, during which real panels are stamped and tools are modified until the desired quality of the final part is reached. Each single tool is released to production through tool buy-off only when the parts produced are compliant with the dimensional tolerances and the targeted quality.

What about the importance of the material type used during tool tryout?

Ideally, the material should be the same in both tryout and production, provided by the same supplier and with the same statistical distribution. Nevertheless, even if this was the case, can you imagine what would happen if the material used in tool tryout had R_m = 400MPa (refer to fig.1)?

In this case, the tools would be adjusted to produce panels based on material property with roughly a 2% chance of being used in production! Actually, if we assume that the material used in tryout has $R_{p0.2}$ = 225MPa, the chances of using the same material in production is now 2% x 50% = 1%.

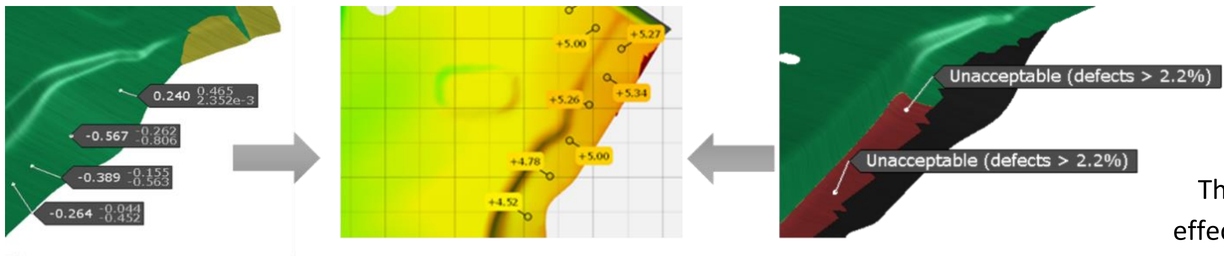
Again, this does not mean that we will need to scrap 99%. Rather, in 99% of the cases, we cannot know how the material will behave during production, as the properties change from coil to coil and even within the same coil.

By the way: just imagine the math involved to determine all of the remaining combinations!

If this were true, the question would become: “How could we ever make cars?” Fortunately, there is no black and white engineering process – but we should think about the costs involved.

As long as the engineered process is sensitive to material property variations, the risk of issues arising in tool tryout and production is particularly high for aluminum or high strength steel grades.

An example of this scenario is shown in the image below. The common engineering approach showed good results, but fortunately (or unfortunately, depending on perspective), an unacceptable amount of springback was detected during tool tryout by measuring the scanned part. A stability check of the engineering results was then conducted to identify the root cause and countermeasures, which highlighted possible issues due to material variation. They showed an acceptable process stability (w.r.t. springback) in the area where in reality, the result was not acceptable.



Common engineering approach Springback Results

Springback measurement of the real stamped panel

“Too Late” Springback stability check

The effect experienced by the uncertainty of material property variations (which cannot be avoided due to the way material is produced) can only be reduced to a minimum by evaluating the process stability. The typical results produced by a single set of simulation parameters (e.g., formability, splits, wrinkles, springback, etc.) – despite incorporating lots of engineering data – ignore the noise (variation) effect generated by the material properties.

Adopting additional analysis criteria becomes even more important if we consider that other parameters (e.g., thickness and friction) are not constant in reality either, but have to be taken into account in the stability check as well.

Engineering a process that is insensitive to material parameter variation means eliminating a *dangerous* variable on your production line. Of course, there are variables we cannot control and materials must sometimes be taken “as is”, so there will always be some aspect of dealing with matters once it arrives.

There will consequently be adjustments made during production, a number of shut downs, scrap, etc. – in short, it is an issue of cost and time.

The goal of process engineering is to develop a stamping process capable of producing not a single part but 200,000 parts (for example) at the most manageable cost. To achieve this goal, the stamping process needs to be **designed for production**. This is only possible when we simulate the real production conditions, considering all known parameter variations that cannot be eliminated since they are part of the process itself.

By Gianfranco Ruggiero and Francesca Tagliafierro, AutoForm Italy

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