Optimization of the process robustness of the stamping of complex body parts with regard to dimensional accuracy

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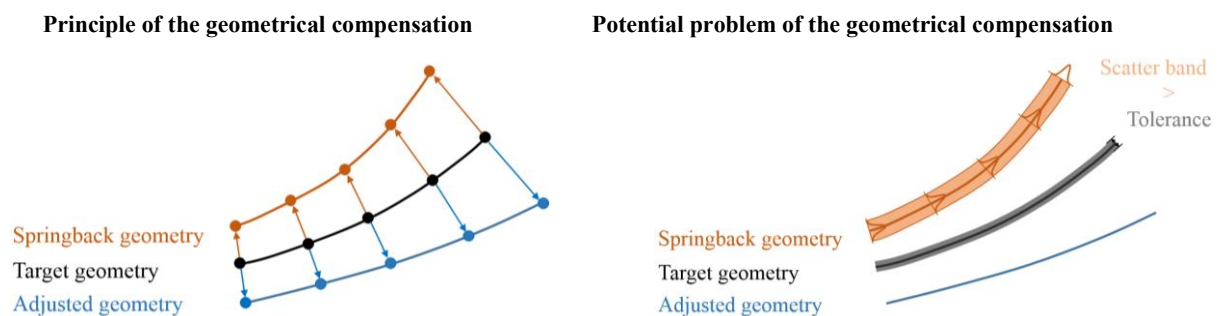[2] inigence gmbh, Bernbachstr. 36, 74626 Bretzfeld, Deutschland

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Abstract. The need for car body structures of higher strength and at the same time lower weight results in serious challenges for the stamping process. In order to produce design conform parts the stamping dies must be adjusted by the amount of the springback in the opposite direction. This approach can only be successful, if the springback only ranges in a certain bandwidth in series production. To do so, it must be fulfilled that for a common spread of input process parameters first of all the draw-in of the flange edge of the drawshell may not reach the drawbeads, secondly material failure by locally increasing strain may not occur at any possible parameter set and last but not least the location of the part in the respective follow-up operation may not vary in such a way that the springback is being affected considerably. After the three basic requirements have been fulfilled the effect of the integral of the elastic strain energy in bending areas has to be minimized by increasing the tensile stress to a maximum. As a result of that the scatter of the bending springback is being reduced.
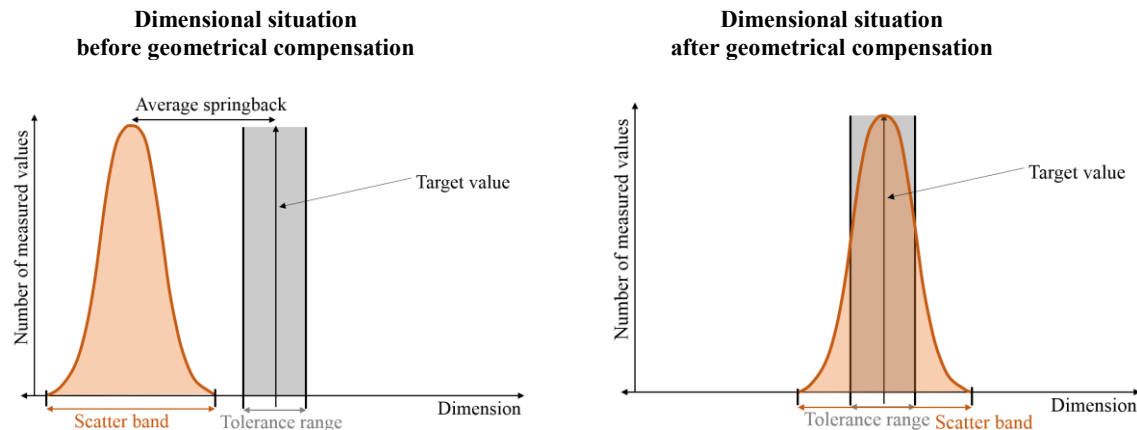
1. Introduction

Springback is the change of geometry which occurs in stamped parts during the opening of the tools, due to the release of elastic energy. The results are deviations from the target geometry. The respective parts are mostly out of dimensional tolerance, which causes quality problems and difficulties in the assembly process. The common approach to compensate that springback is to modify the die face geometry of the stamping dies more or less by the amount of the springback in the opposite direction. Assuming that the springback should remain the same after compensation the final product shape shall closely approximate that of the target product. This approach has the potential to compensate springback almost completely (Figure 1).

Figure 1.   Principle of the geometrical springback compensation and belonging potential problem

In series production the springback moves in a certain bandwidth as a result of scattering process and material parameters. The approach of the geometrical compensation (=process centering) can only lead to sufficient results, if the scatter of the springback does not exceed the given tolerances. Otherwise, even after the geometrical compensation, a certain number of parts will probably be out of tolerance (Figure 2).

Figure 2. Influence of the scatter band of the springback on the dimensional situation before and after geometrical compensation

Today´s software tools for sheet metal forming allow to calculate the expected bandwidth of the springback in series production, even before the physical tools are available. This allows the process planners to evaluate at an early stage whether a geometrical compensation has the potential to provide the intended results.

The real problem occurs, when the calculated scatter of the springback exceeds the given tolerances, which means that a sufficient process potential is not given. Until today there is little knowledge what to do if the springback does not move in the required bandwidth and the given tolerances cannot be achieved.
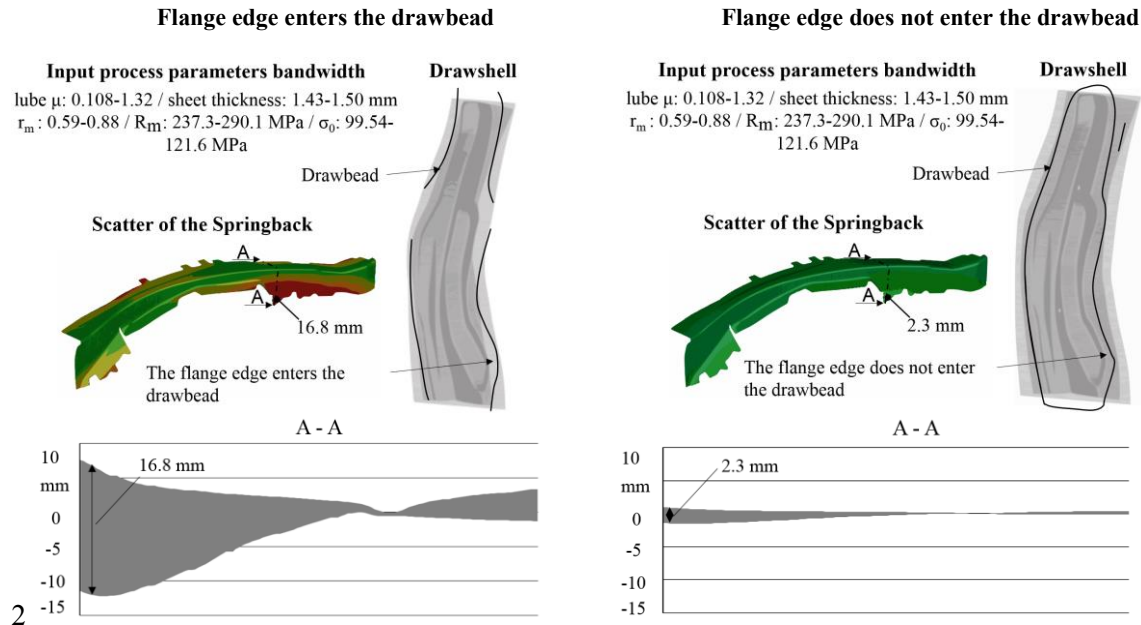
2. Basic requirements for a robust process with regard to springback

In order to develop a guideline for the optimization of the respective process robustness a FE-based investigation has been done on several body parts taking into account the scatter of process parameters as they would be expected in real series production. The investigation showed that three basic requirements must be fulfilled in order to obtain a fundamental precondition for a robust process with regard to springback.

2.1 Safe distance of the draw-in of the flange to the drawbeads

A basic key fact is that springback is a function of stress and strain. Both – namely stress and strain – are significantly dependent on the draw-in of the flange. The draw-in of the flange can be controlled by drawbeads and by local, regional and global blank holder force. A dramatic change in flange draw-in and thus in springback mostly occurs, when the flange edge enters the drawbead.

In the shown example of a *longitudinal beam* (material *AlMg3.5 / EN AW-5753*) the scatter of the springback amounted up to 16.8 mm in the case in which the flange edge entered the drawbead, but it amounted to only 2.3 mm, when the flange edge did not enter the drawbead (Figure 3).
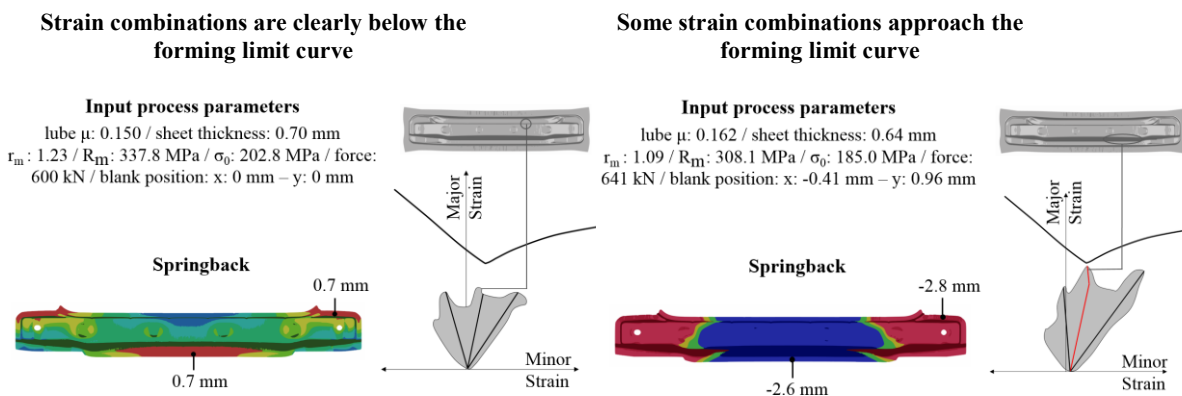
Flange edge enters the drawbead

Flange edge does not enter the drawbead

Input process parameters bandwidth

lube μ: 0.108-1.32 / sheet thickness: 1.43-1.50 mm
r_m : 0.59-0.88 / R_m: 237.3-290.1 MPa / σ_0: 99.54-121.6 MPa

Drawshell

Drawbead

Scatter of the Springback

16.8 mm

The flange edge enters the drawbead

A - A

Input process parameters bandwidth

lube μ: 0.108-1.32 / sheet thickness: 1.43-1.50 mm
r_m : 0.59-0.88 / R_m: 237.3-290.1 MPa / σ_0: 99.54-121.6 MPa

Drawshell

Drawbead

Scatter of the Springback

2.3 mm

The flange edge does not enter the drawbead

A - A

Figure 3. Influence of the entering of the flange edge to the drawbeads on the scatter of the springback

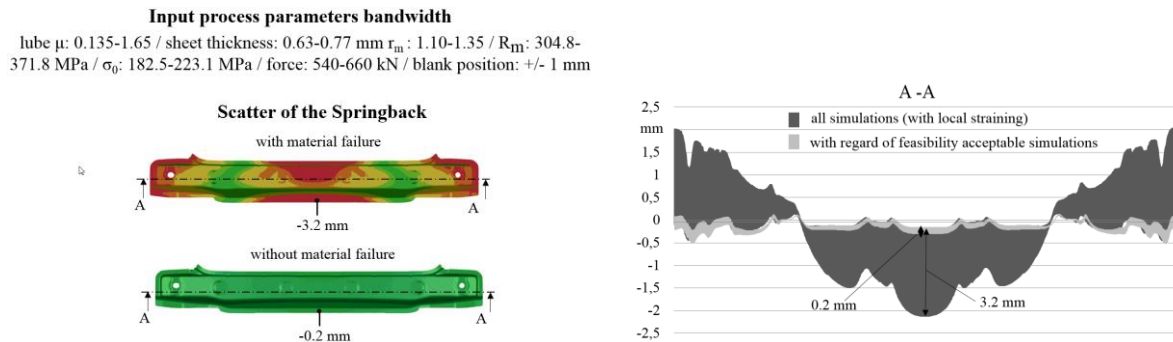*2.2 Safety against material failure by locally increasing strains*
In the previous section we have defined a safe distance of the drawn-in flange edge to the drawbeads as the prioritised requirement for a robust process with regard to springback. The second main requirement is, that for a common spread of input process parameters strains near the forming limit curve are avoided, because the consequence would be locally concentrated strains. These in turn can significantly influence the springback behaviour not only with regard to the amount of springback but – which is even worse – in its springback characteristics, which means that the kind of springback (e.g. bending or torsion) can vary at different process parameter sets.

Figure 4 shows the forming limit diagrams and the simulated springback for two different parameter sets of a *radiator supporter* (material *CR180*). For the parameter set on the left side all strain combinations are clearly below the forming limit curve. The maximum amount of the maximum springback of the *radiator supporter* is about 0.7 mm (Figure 4). For the parameter set shown on the right side some strain combinations approach the forming limit curve. In result of that some strain paths are nonlinear which can be seen as a hint for local straining. The amount of the maximum springback has increased significantly to 2.8 mm due to dramatic change of strain distribution (Figure 4).

Strain combinations are clearly below the forming limit curve

Input process parameters

lube μ: 0.150 / sheet thickness: 0.70 mm
r_m : 1.23 / R_m: 337.8 MPa / σ_0: 202.8 MPa / force: 600 kN / blank position: x: 0 mm – y: 0 mm

Springback

0.7 mm

0.7 mm

Major Strain

Minor Strain

Some strain combinations approach the forming limit curve

Input process parameters

lube μ: 0.162 / sheet thickness: 0.64 mm
r_m : 1.09 / R_m: 308.1 MPa / σ_0: 185.0 MPa / force: 641 kN / blank position: x: -0.41 mm – y: 0.96 mm

Springback

-2.8 mm

-2.6 mm

Major Strain

Minor Strain

Figure 4. Influence of material failure by locally increasing strains on the springback

The result of the robustness analysis confirms the results of the of the reference simulations (Figure 5). The scatter of the springback can increase significantly, if strain combinations approach the forming limit diagram.

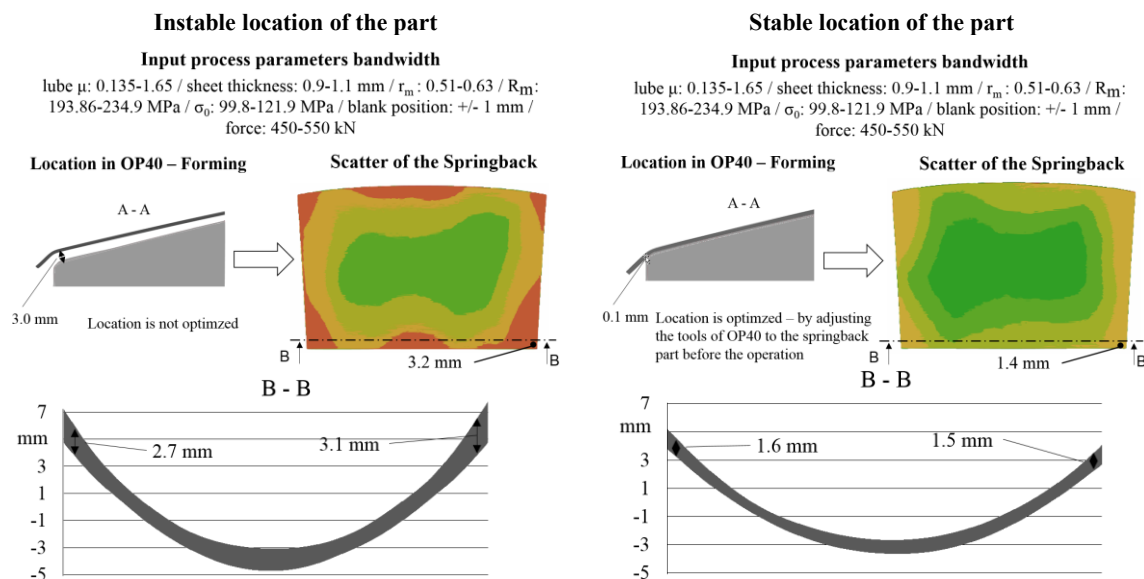**Figure 5.** Influence of material failure by locally increasing strains on the scatter of the springback

2.3 Stable location of the part in the respective follow-up operation

The third requirement, which must be fulfilled, is that the location of the part in the die is sufficiently stable and repeatable. Otherwise even small changes of the geometry of the drawshell can influence the location of the part in the follow-up operations significantly. In turn the forming process can be affected in such a way, that (significant) changes of the respective springback occur.

Figure 6 shows the scatter of the springback of a *roof* (material *EN-AW6014*) for two different simulations with identical input parameter set. The only difference between the two simulations is that for one simulation the location of the part in the subsequent forming operation has been optimized. This was achieved by fitting the tool design to the springback part before executing the respective forming operation. Among experts this fitting is well-known as the so-called drawshell approach, as the subsequent operations are adjusted to the respectively arriving part.

The maximum scatter of the springback for the reference tool geometry is about 3.2 mm. For the optimized tool geometry the scatter of the springback could be reduced to only 1.6 mm which corresponds to a reduction of 50%!

This result shows that a stable and repeatable location of a part in follow-up forming operations is from key importance for a robust process with regard of dimensional accuracy.
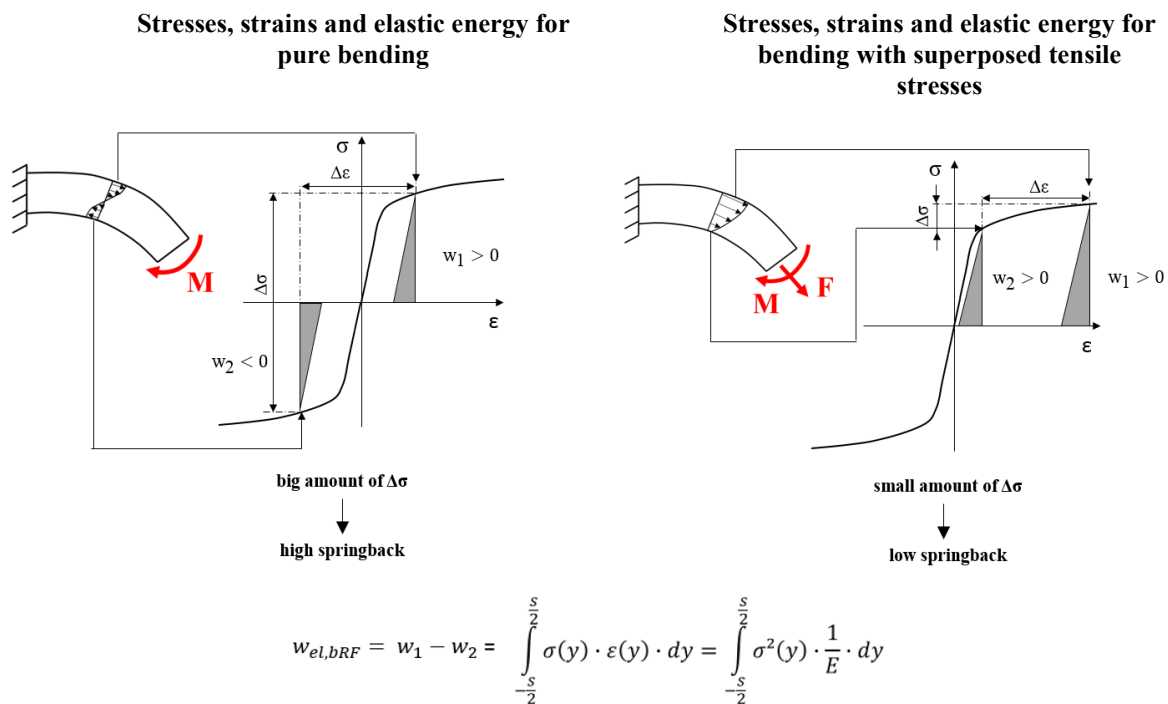

Figure 6. Scatter of the springback with basic and drawshell-compensated geometry

3. Optimization of the process robustness

In the previous sections the basic process requirements for a robust process with regard to springback have been discussed. If these requirements are fulfilled a well-directed reduction of the present scatter of the springback can be realized from the beginning of the planning process. Subsequently it will be shown how the scatter of the springback can be further reduced through actively influencing the stress and strain distribution.

3.1 Influence of the elastic strain energy in bending areas on the process robustness

The generally accepted knowledge about the appearance of springback is a consequence of membrane and bending stresses. As a consequence of that the springback of parts with a high amount of bending can be reduced by minimizing the effect of the integral of the elastic strain energy by increasing the tensile stress [1]. By doing so the stress difference between the lower and upper side of a sheet and thus the stress gradient dσ/ds in bending areas and finally the bending springback is being reduced significantly, Figure 7.

Stresses, strains and elastic energy for pure bending

Stresses, strains and elastic energy for bending with superposed tensile stresses

$$w_{el,bRF} = w_1 - w_2 = \int_{-\frac{s}{2}}^{\frac{s}{2}} \sigma(y) \cdot \varepsilon(y) \cdot dy = \int_{-\frac{s}{2}}^{\frac{s}{2}} \sigma^2(y) \cdot \frac{1}{E} \cdot dy$$
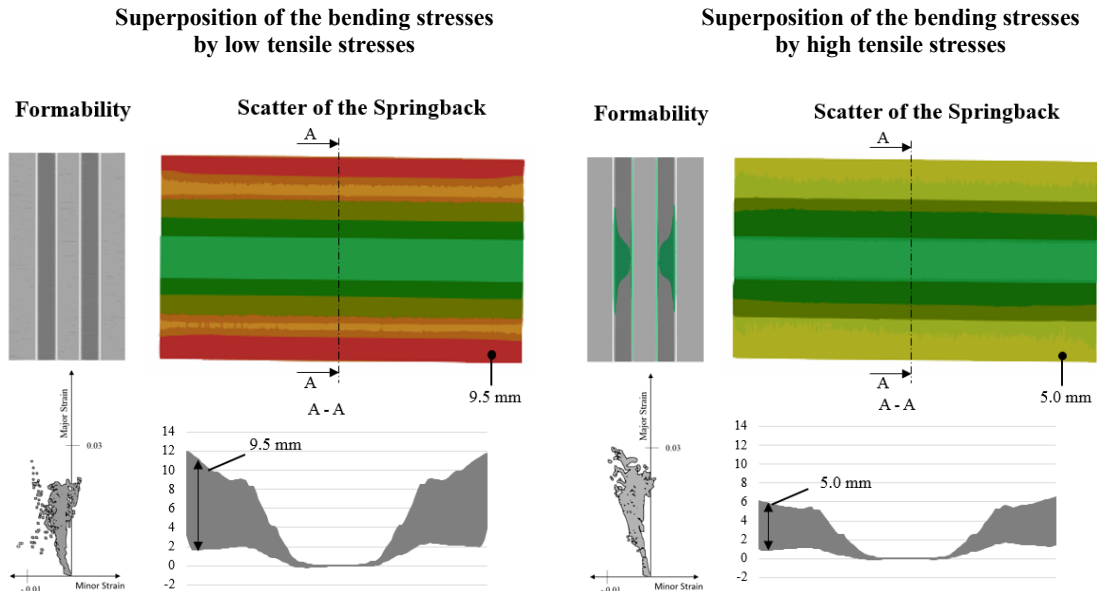
Figure 7. Stress difference from the lower to the upper side of the sheet and elastic strain energy [1]

In the course of the presented investigation the influence of the elastic strain energy on the process robustness has been analyzed. In the first step a *top hat profile* (material *HDT1200M*) has been chosen as an example due to the large amount of the bending springback. The *top hat profile* has been simulated with two different restraining forces for the used drawbeads. In consequence of that two completely different situations with regard to elastic strain energy before the opening of the virtual tools have been created. Based on the two simulation setups two robustness analyses have been carried out. To do so the input process parameters have been varied in 112 simulations in the bandwidth shown in Figure 8. Figure 8 also shows the formability, the forming limit diagram and the calculated scatter of the springback for the two different simulation setups.
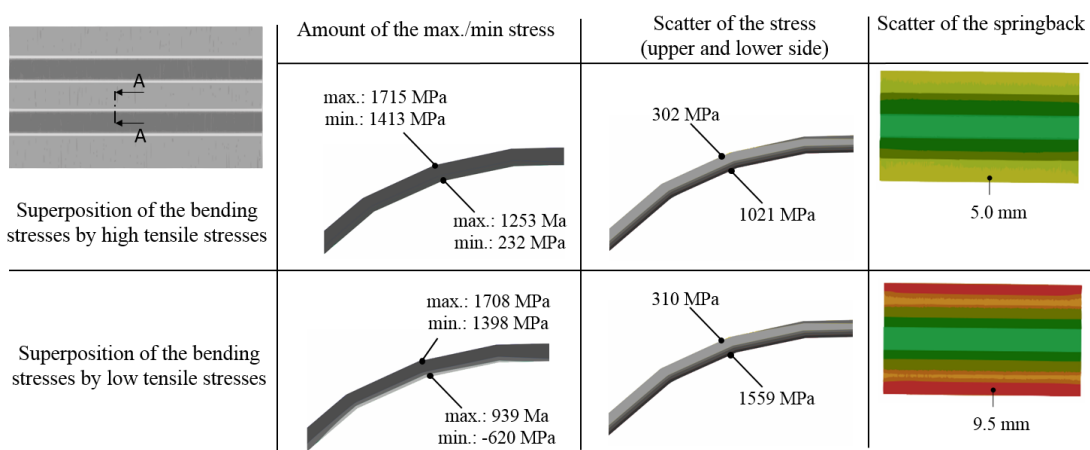
Input process parameters bandwidth

lube μ: 0.135-1.65 / sheet thickness: 0.45-0.55 mm / r_m : 0.64-0.96 / R_m: 1234-1458 MPa / σ_0: 1012-1236 MPa /
blank position: +/- 1 mm / pressure: 22.5-27.5 MPa

Figure 8. Effect of the integral of the elastic strain energy on the scatter of the springback of a *top hat profile*

The maximum scatter of the springback, which occurs at lower superposed tensile stresses, amounts up to 9.5 mm, whereas in case of higher superposed tensile stresses the scatter of the springback could be reduced to 5.0 mm, which corresponds to a reduction of nearly 50%!.
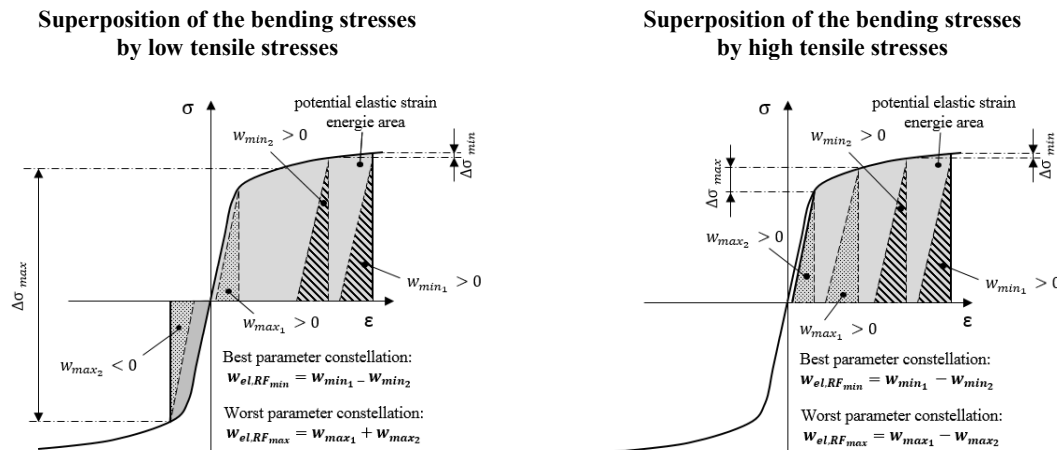
Figure 9 shows the scatter of the stresses at the lower and the upper side of the sheet. In addition Figure 9 shows the stresses for the respective parameter set with the highest and lowest amount of springback.

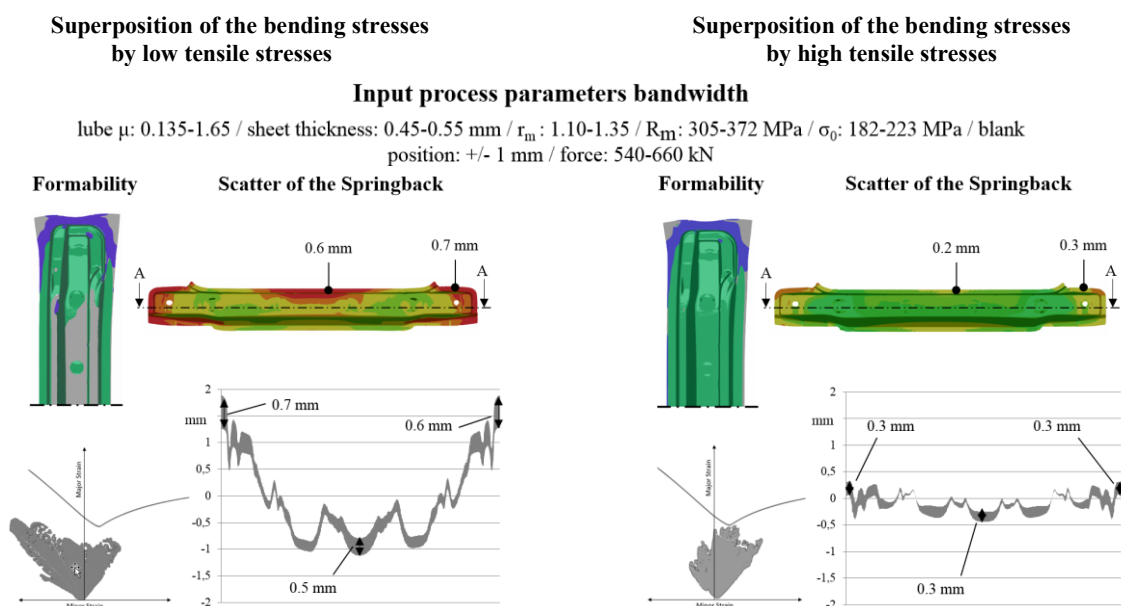**Figure 9.** Scatter of stresses at the upper and lower side of the sheet

The scatter of stresses on the upper side of the sheet is only affected minimally by the variation of the restraining forces of the drawbeads. It could be reduced from 310 MPa (min. 1413 MPa – max. 1715) to 302 MPa (min. 1398 MPa – max. 1708 MPa) only. The scatter on the lower side of the sheet however is being affected significantly. It could be reduced from 1559 MPa (min. -620 MPa – max. 939

MPa) to only 1021 MPa (min. 232 MPa – max. 1253 MPa). But what is even more important than the reduction of the scatter of stresses is the shift to higher values. The consequence of that shift is being described with the help of Figure 10. By the reduction of the scatter of the stresses and the shift to higher values the bending stresses are superimposed by tensile stresses for all relevant parameter sets. In consequence the stress gradient dσ/ds and finally the springback are reduced <u>for all relevant parameter sets.</u>

Figure 10. Influence of the stress superposition on the elastic strain energy area

To confirm the influence of tensile stresses on the scatter of the springback for a complex body part a *radiator supporter* has been investigated (material *CR180*) (Figure 11). As in the previous case of the *top hat profile* the effect of the elastic strain energy has been influenced by superposing different tensilestresses, using different restraining forces for the used drawbeads. The maximum scatter of thespringback, which amounted up to 0.7 mm occurs in case of low tensile stresses. The minimum scatterof the springback, which amounted up to only 0.3 mm occurs in case of high tensile stresses. For theshown *radiator supporter* the scatter of the springback has been reduced by 57%.

Figure 11. Influence of the elastic strain energy on the scatter of the springback of a *radiator supporter*

4. Conclusion

In order to produce design conform parts the stamping dies must be adjusted more or less by the amount of the springback in the opposite direction. This approach can only be successful, if the springback only moves in a certain bandwidth in series production. In this paper the basic requirements for a robust process with regard to dimensional accuracy of body parts have been presented. In addition to that the elastic strain energy before springback have been proven to have a significant influence on the process robustness with regard to springback.

The first requirement, which must be fulfilled, is that the draw-in of the flange edge may not reach the drawbeads for all relevant parameter sets. Using the example of a *longitudinal beam* the scatter of the springback could be reduced from 16.8 to 2.3 by fulfilling this requirement.

The second requirement is that material failure by local straining may not occur at any possible parameter set. Using the example of a *radiator supporter* the scatter of the springback has been reduced from 3.2 mm to 0.2 mm by fulfilling this requirement.

Last but not least the location of the part in the respective follow-up operation must be optimized in order to secure a stable and repeatable location of the part in the die. As a consequence the scatter of the springback of the analyzed *roof* could be reduced from 3.2 mm to 1.4 mm.

It has been shown that after the three basic requirements are being fulfilled the effect of the integral of the elastic strain energy in bending areas has to be minimized by increasing the tensile stress to a maximum – either by higher restraining force of the drawbeads or by modified die geometry / die addendum – to finally reduce the scatter of the bending springback effect. By the reduction of the scatter of the stress difference and a shift to higher values the bending stress is being superimposed by tensile stresses in such a way that the stress gradient $d\sigma/ds$ is reduced significantly <u>for all relevant parameter sets.</u>

References

[1]   Birkert A, Straub M and Haage S 2013 Umformtechnische Herstellung komplexer Karosserieteile, Springer-Verlag Berlin Heidelberg pp 304-307