Simulation aspects for the application of high strength steel materials in forming processes

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High-strength, cold-formable steels offer great potential for meeting cost and safety requirements in the automotive industry. In view of strengths of up to 1200 MPa now being available, some aspects need to be analyzed and evaluated in advance when designing with these materials. In addition to an early assessment of crash properties, it is also highly important to design the forming process to match the material potential. Caused by the micro-structure of the different steel grades available, significant differences in some of the main forming operations can be observed. Characterizing fracture behavior is therefore becoming increasingly important for the reliable prediction of the material behavior in FE simulation. For this reason, fracture models have been increasingly integrated into component design, but these in turn have to be tailored to material behavior. ThyssenKrupp Steel Europe started a process to characterize the fracture behavior of newly developed materials and in the long term to use these information in customer-relevant FE material models. The design and planning of forming processes also need to be matched to the properties of the materials. For example, many materials beyond a tensile strength of 800 MPa display a greatly increased risk of edge failure or surface defects during forming. In designing processes, mainly based on FEM-simulations, therefore, it is important to pay particular attention to the applied radii and to blank shape.

KeyWords: high strength steel, simulation, fracture, hole expansion

1 Introduction

At the start of the 21.Century, the simulation of crash processes and of sheet forming processes using virtual methods to evaluate material behavior had already taken an important position in the introduction of new products in the automobile supplying and manufacturing industries. As a result, continuously increasing demands are made on the strength of the material and also on the expectancy of the results of the simulation [1]. In order to further develop the quality of these simulations, an evolution in numerous experiments and models began which was targeted at the sustainable improvement in prognoses and in particular at criteria to determine quality such as elastic recovery and the danger of failure. In view of the expansion of the material spectrum with strengths of up to 1900 MPa for hot forming parts and approx. 1200 MPa up to 1400 MPa for cold forming parts whilst at the same time realizing weight reduced constructions with thinner sheet thicknesses, the simulation must fulfill a multitude of criteria in order to reach the targeted quality required.

2 The motivation for further evaluating criteria

The aim of each simulation application is to recognize any possible problems which may arise as early as possible during the planning of a component.
However, different material concepts do react differently to the typical loads to which they are exerted, which cannot always be determined from the key values of the tensile test. By means of the multiple illustration of the entire process chain from forming to post-forming through to crash, the depth of simulation increases dramatically. In view of the high number of demands made on the materials, classic procedures such as the application of admissible thinning, the comparison with forming limit curves or the pure monitoring of elongation after fracture do not alone give a clear indicator for the suitability for series production of a selected process or the launch of a component, which owing to the increased efforts towards weight reduction have been brought to their technical limits. The introduction of high strength multi-phase steels have shown that in addition to failure by exceeding the forming limit curve, there are other areas where e.g. a drawn component produced in series can fail (Fig. 1). Particularly with respect to bending behavior or sensitivity to edge fracture, there is an increasing necessity to make the interpretation of the results easier for the operator and thus provide assistance in process design.

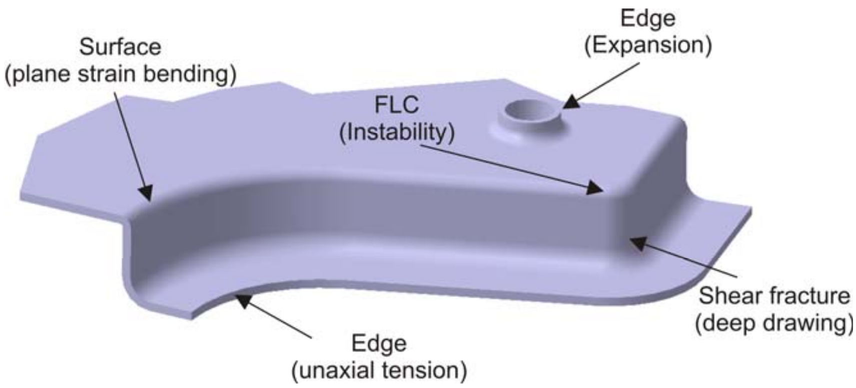

Fig.1: Forming conditions always require the evaluation of the forming capacity

3 Forming properties of high-strength steels

In general the forming potential of a material is characterized by the tensile test results in combination with the forming limit curve. The use of multiphase steels in automotive production applications in recent years has shown that attention should also be paid to edge stretchability and flangeability as an important forming mode. In contrast to mild and micro-alloyed steels, which have a mainly ferritic microstructure, advanced high-strength steels have a wide range of microstructural composites in order to combine high strength and good formability, due to the high work hardening potential. In many cases, the cracking of stretch-formed edges is a common failure mode for multiphase steels [2]. Typical examples are load-relieving holes and flanging at cutouts in sheet metal blanks. Figure 2 shows the forming capability of different grades in a flat hole expansion test after a shear-cutting operation to stamp the hole. For the CP-W 800 material there is hardly any impact of the cutting operation to the hole expansion. The reason for this is a rupture near the edge, which limits the expansion process when the forming limit curve is reached. In comparison to this the TPN-W 780 loses some of his high forming potential due to the cutting and shows a crack at the edge. Thus a simulation including only the FLC interpretation might oversee the possible edge cracking problem during forming. Performing different experiments like ISO TS 16004 or similar would result in different limiting strain values. This shows the complexity and also the challenge to implement a failure prediction method into FEM programs [3].

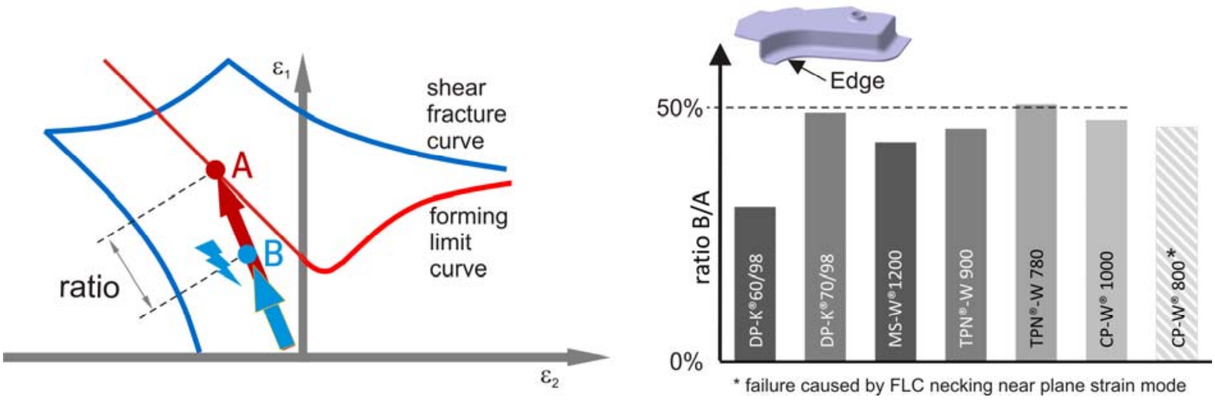

Fig.2: The potential of various materials with in plane edge stretching

A further important aspect especially concerning edge strain distribution is the quality of the cut edge. The shear-cutting process offers several parameters to influence the quality of the cut-edge surface. This can lead to a reduced loss of the forming potential for high strength steels due to shear cutting. For example by using a recutting operation for hot rolled complex phase steel grades the hole expansion ratio can be significantly increased. Using the original hole diameter as a reference, the recutting increases the forming from 50% to nearby 80% hole expansion ratio. On the other side if the cutting parameters are not probable adjusted the hole expansion ratio can be reduced to 30%. By using optimized cutting parameters more robust press shop operation and also more complex shapes can be achieved. In extrusion drawing this can lead to up to 2mm differences in height.

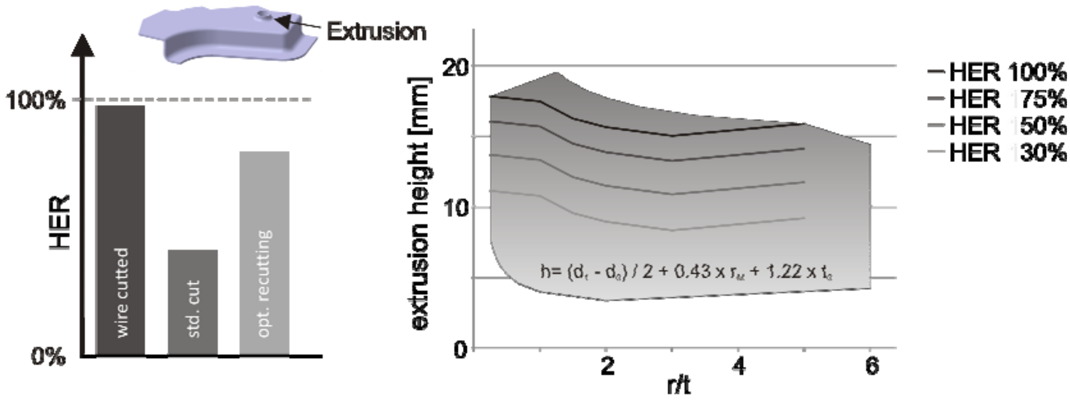

Fig.3: Influence cutting process on hole expansion ratio and extrusion height

Another mode characterizing the forming potential of a material is the shaping of small radii at a part. Here there has been nearly no restriction for a longer time, when the maximum strain for the surface fiber has been around 4 to 5 times higher than critical strain represented by the FLC. With the ultra-high strength materials it has been shown that limiting the maximum surface strain with the FLC is much too conservative [4]. Nevertheless a material specific attention requirement is necessary as can be seen in figure 4. Within the same strength level different forming capabilities in the bending process are obvious when compared to FLC plane strain level.

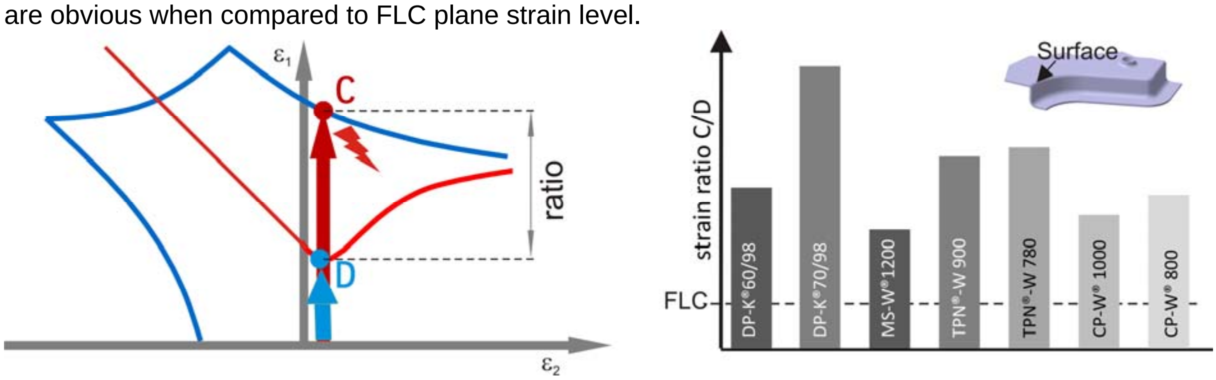

Fig.4: Influences of the micro-structure and material strength on the shaping of sharp radii

As a consequence of the examples discussed here showing the influence of the microstructure on the forming capabilities of a material, additional, material grade specific attention must be given in a simulation process.

4 Current failure models and experiments

Numerous supplementary suggestions [5] exist for different approaches to the holistic evaluation of forming or crash processes. [6]. On the one hand simple methods have been developed for easy application e.g. for real parts. Here a bending or edge FLC serve as the result for the individual limit value of each material. For the industrial application on the other hand, the FEM integrated model is the center of focus. Here the models CrachFEM [7], MMC [8] and GISSMO [9] count among the phenomenological based failure models. The generic structure of these FE models is similar. The evaluation of the damage is effected via critical limits of local elongation or stress through which the failure is initiated. The measure of the damage in this model is constitutively linked to elongation and thus to the fracture strain curve, whereby in addition to the formulation of the failure curve, the model takes into account different approaches respecting the accumulated plastic deformation during the course of the forming history. For all models, however, the fracture strain curve forms the core component. For each model a specific parameter alignment must be determined whereby pre-recorded experimental basic failure data measured in special tests using different test shapes can be used to calibrate all models (Fig. 5). To this end, the measured strain data must be transformed into model-specific stress condition variables. As a result of this complex process, the failure data could have a relatively large scatter band. Thus the operator is placed in the position to adjust the applicable failure curve to his own requirements. In general the above mentioned method based on tried and tested models for the probability of local cracking is suited to evaluate cut edge forming. However, the problem of local elongation resolution on the edge coupled with the lack of knowledge concerning which forming reserves were used in the cutting process still exists.

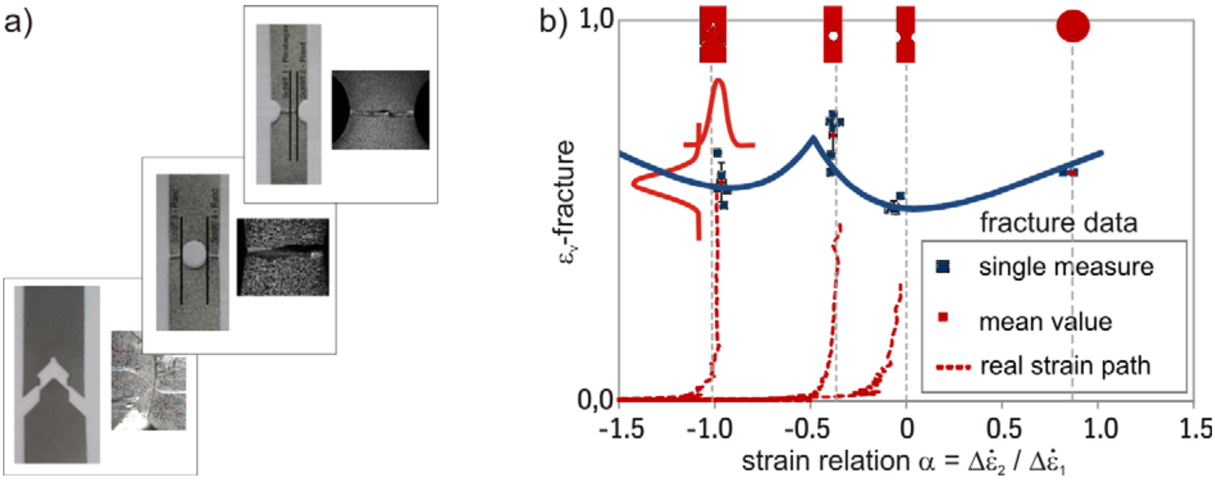

Fig.5: Determining fracture data for the deduction of the fracture curve

However, only using the fracture curve fails to carry out a reliable prognosis re-garding failure. In a further step a model-specific material card has to be compiled. Beginning with the constitutive equation components, which may also have to be adjusted, the model and FE program specific parameters must be optimized. In order to meet the application potentials of the high-strength materials and also to gain a more exact understanding of the materials for particular applications, ThyssenKrupp Steel Europe has systematically integrated the process for experimental data finding, evaluation and transfer into the FEM in house over the last 10 years.

5 Examples for the application of fracture models

In order to plan processes with high-strength steel products, their property profile should as a matter of principle be compared with the process requirements. Each feasibility study must take into account just which types of load are to be expected dependent on the forming process planned and the material to be investigated, figure 6 a). Only in a few of the above mentioned load cases can the use of a comparative value in combination with the correct evaluation of an FEM already offer a helpful procedure. If the geometry of a component is marked visually with small radii, then the material-specific suitability regarding the maximum tolerable elongation on the outer surface related to the limit elongation at the beginning of possible necking should be taken into account in the analysis. This ratio at least shows the tendency or indicates that certain materials should be given preference for this type of load [10]. This process should at least secure that neither the model nor the operator only evaluates the elongation in the membrane level of a shell element but also extra targets the elongation in the outer layer of the shell near the surface. In particular with changes in material thickness but with otherwise the same boundary conditions, the load limits of the materials could lend them-selves to completely different interpretations, compare figure 6 b). As dependent on the forming process, e.g. with crash forming, small radii can form both temporally and locally during the forming process, the evaluation of the history of the deformation becomes relevant here. This procedure requires no great effort, but owing to its step for step approach is not particularly user friendly. In some cases it may become necessary during the course of the investigation to change to a more complex and higher quality failure model. In the case where numerous failure potentials are identified, the use of rupture models provides a user friendly solution as many of the above mentioned aspects are taken into account and the results shown in the familiar visual form using color codes. The necessity of using this model is particularly recommended when plastic deformation under shear stress is found. Fig. 7 shows as an example the comparison between a simulation and a component test with strong local shear stress, which finally led to the failure of the component.

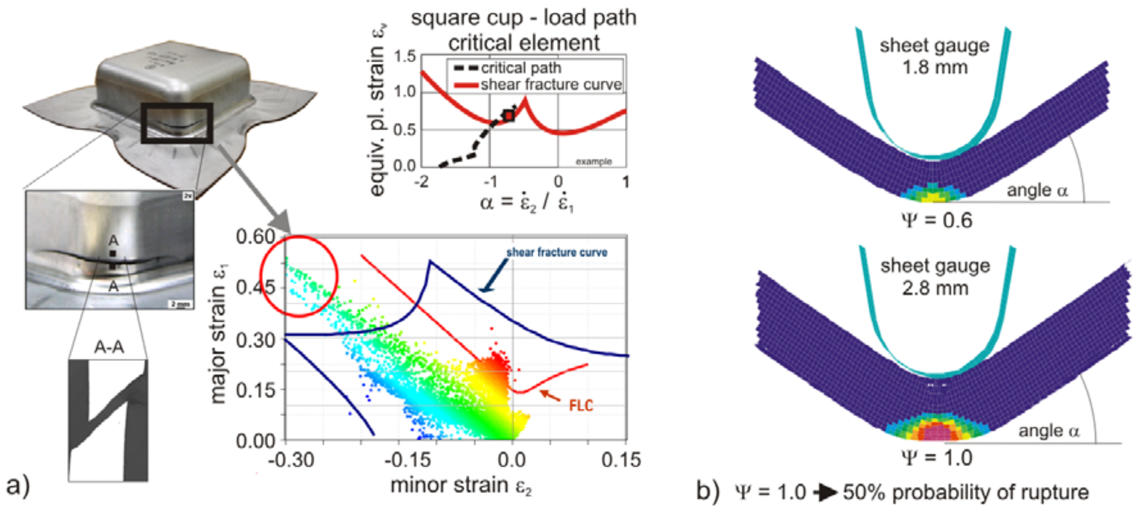

Fig.6: Examples for the application of a failure model in forming operations

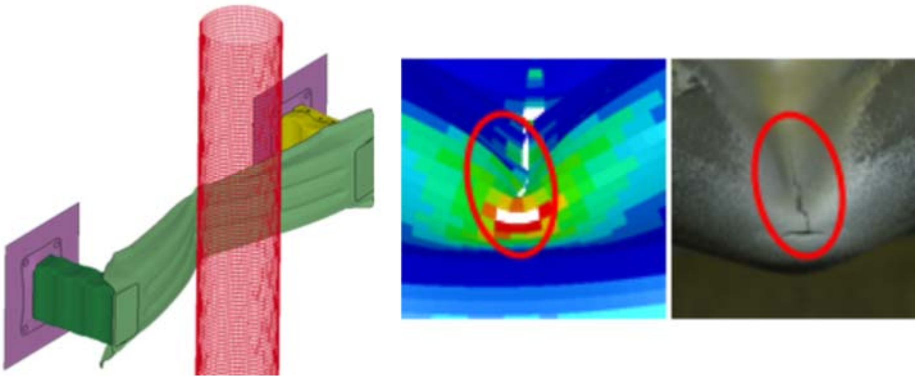

Fig.7: Example for the application of a failure model for the fracture prognosis in crash simulation

6 Conclusions

The ever increasing demands on the function and manufacture of components coupled with the pressure towards weight reduction has led to the comprehensive application of high-strength cold and hot formed steel materials. With the safe design of these materials very much in mind, a reliable interpretation of the simulation results in their areas of application is essential. For forming, individual, possibly critical types of load can be met in an initial step together with other, further, material-specific evaluation criteria. However, for more complex processes and material load histories, modern failure models are available and their use offers an impression about the safety of the process which cannot be gleaned from the load conditions represented by the FLC [11]. The same applies for the analyses of crash procedures, whereby the use of the model is even more advanced. Many of the points mentioned are current themes in research work which are closely accompanied by industry to ensure the direct transfer into their own processes.

7 Literature

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