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Virtual Prototyping of Lightweight Designs Made with Cold and Hot Formed Tailored Solutions

Eren Billur[1], Harald Porzner[2], Taylan Altan[1]

[1]Center for Precision Forming, The Ohio State University, 339 Baker System, 1971 Neil Ave., Columbus, OH 43210 USA.
[2]ESI North America, 32605 W. 12 Mile Road, Suite 350, Farmington Hills, MI 48334 USA.

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Abstract

Tailored cold and hot formed solutions are the key to the lightweight construction of the future vehicles. Only tailored solutions allow the combination of soft and hard zones for the best possible crash performance and minimum weight. The safety cage of future vehicles may completely be designed with hot formed components. In order to achieve the desired properties of the component, a heat treatment operation is necessary, and it comprises a significant part of the hot forming process. This poses additional challenges to the automotive industry as the heat treatment process is a function of many parameters and depends strongly on the forming process. In addition, only perfectly heat-treated parts will fulfill specifications.

Virtual Prototyping makes sure that component manufacturing and assembly processes yield to the designed tolerances and crash performance. ESI GROUP aims at providing all necessary tools for virtual prototyping of lightweight constructions designed and assembled with tailored solutions, in particular hot forming. This paper outlines what is needed for realistic virtual prototyping, and what is the status of the simulation solution. Validated realistic engineering examples are used to illustrate the capabilities in the field of virtual die design, forming, quenching, cooling channel engineering, assembly and product performance.

Introduction to Hot Forming of High Strength Steels

Higher strength steels can help reduce weight by reducing the blank thickness. However, as strength increases, formability decreases (which leads to splits), and the force required for forming increases. Maintaining dimensional tolerances is also an issue due to severe springback, Figure 1 [1].

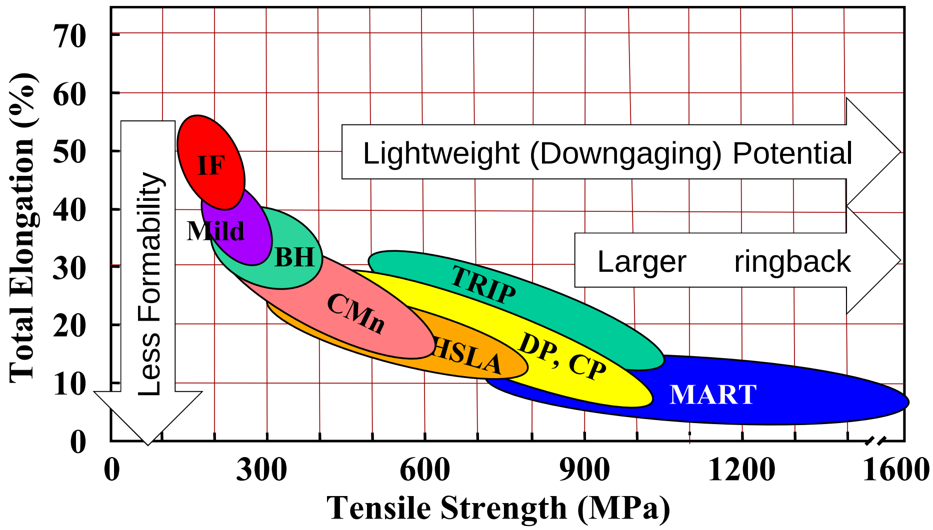


Figure 1: "Banana Curve": higher strength steels have lightweight potential, but limited formability and hard to control springback [1].

Hot forming (also known as press hardening or hot stamping) is a relatively new technology which allows ultra-high strength steels (typically 22MnB5) to be formed into complex shapes, which is not possible with regular cold stamping operations [2]. This is achieved by two methods [3]: (1) Indirect Process: the blank is formed, trimmed, and pierced in cold condition (i.e., state 1 in Figure 2). It is later heated and quenched in a die to get high strength properties; (2) Direct Process: the unformed blank is heated in a furnace, formed in hot condition (state 2 in Figure 2), and quenched in the die to achieve the required properties.

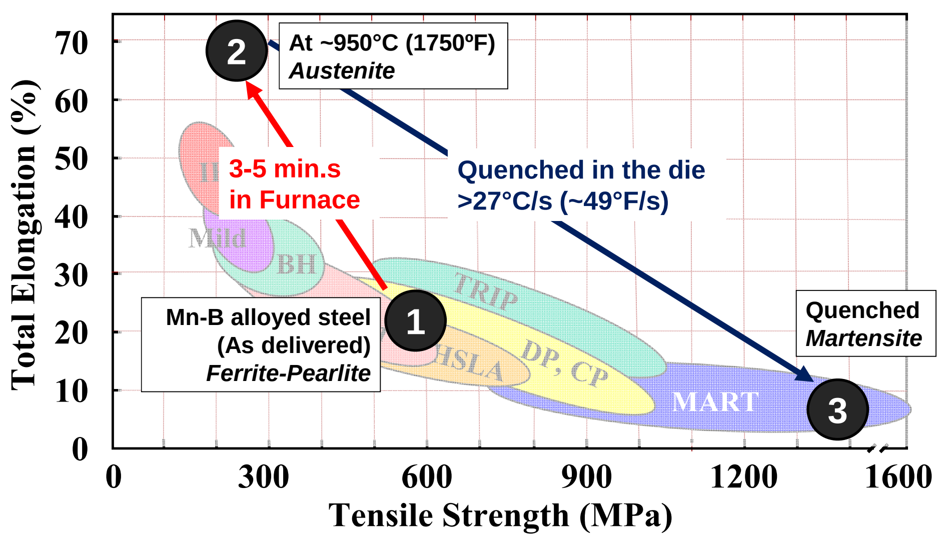


Figure 2: Summary of hot forming process.

Need for Tailored Properties

Tailored parts have been commonly used in the automotive industry to reduce the weight of components, simply by either: 1) eliminating the need for reinforcement and/or 2) to reduce the thickness in low-load areas. Tailored blanks can be made by, welding (Tailor Welded Blanks: TWB) or rolling (Tailor Rolled Blanks: TRB). TWBs can be composed of (1) two or more different thicknesses, (2) two or more different alloys (i.e., typically high strength steel with mild steel), or (3) a combination of both. TRBs are made with the same material with variable thickness profiles [4-6].

With hot stamping, generally ultra-high strength (in the order of *UTS > 1400 MPa (>200 ksi)*) is achievable. However, high strength causes several problems, especially in automotive applications: (1) strength reduces the elongation and thus the energy that can be absorbed and (2) welding of very high strength steel to mild steel creates a heat affected zone which initiates cracks. Use of TWB's and TRB's in hot stamping is recent technology, applied since 2008 and 2006, respectively [4, 7]. Hot stamping makes a new type of "Tailored Blank" possible, one where the final microstructure (and therefore the strength and elongation properties) can be tailored in a single blank, Figure 3c [5].

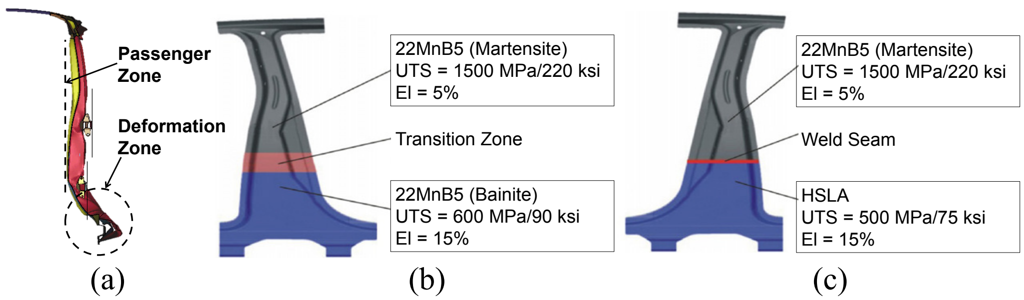


Figure 3: (a) Side view of a B-pillar after crash [8]. (b) Tailored properties or (c) TWBs may improve elongation in the deformation zone [5].

Challenges in Modeling and Analyses

Typical cold forming operations require one flow stress curve, anisotropy coefficients (r_0, r_{45} and r_{90}), friction parameters and yield criterion (Hill 48, Barlat 90, etc.). However, hot forming processes require more input parameters since there are: 1) mechanic, 2) thermic, 3) metallurgic and 4) fluid mechanic fields involved in the process and are all interrelated as illustrated in Figure 4 [9].

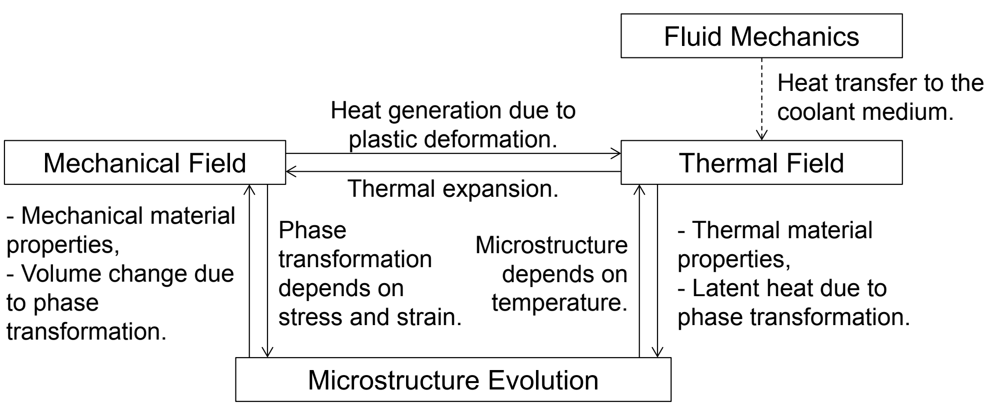


Figure 4: Multiphysics problem of hot forming [9].

Simulation of hot forming process can be divided into 4 stages. In each stage, different physics are involved. The gravity stage is modeled as implicit and only uses a mechanical field. Holding and forming stages have both mechanical and thermal fields - forming has to be completed while the blank is still at the austenite phase and no phase transformation is desired. The quenching stage has thermal and microstructure evolution fields. Fluid mechanics is not included in quick simulations so that costly couplings are avoided. Once the die face is designed by FEA using shell elements, cooling channels can be designed with volume elements.

Engineering Goals with Virtual Prototyping

Engineers can accomplish the following goals by means of virtual hot forming engineering:

- Ensure that no cracks or wrinkles occur during the forming process.
- Ensure that the forming process occurs in a good process window. This is in particular important for Zn coated blanks.
- Ensure that the forming process is completed before phase transformations start. The forming should occur in the austenite state, where material characteristics are similar to standard draw quality steel.
- Ensure that there is a proper time range between the end of forming and the start of phase transformations.
- Ensure that cooling rates match the process design and provide a safe process window.
- Ensure that phase transformations are completed when the part exits the die. Otherwise, ongoing phase transformations will cause severe distortion in the fully hardened part.
- Ensure that the part has the specified hardness value when cooled to room temperature.
- Minimize the part cycle time.
- Optimize material usage.
- Eliminate or minimize additional trimming operations.
- Optimize size and location of cooling channels.

Virtual Press Shop: Hot Stamping and Tailored Parts

Hot forming dies typically cost more than those for cold stamping due to (1) complex cooling channels drilled in, (2) expensive hot forming tool materials with high thermal conductivity (such as H11, H13 and their variations), and (3) more intense die spotting. Particularly with tailored quenching dies where dies in contact with "hard zones" are water cooled and areas in contact with "soft zones" are cartridge heated, late changes in tooling are expensive.

Virtual press shop can help discover if the dies and the process will yield useful parts. A useful part can be defined as one without (1) cracks/splits, (2) necking (excessive thinning), and (3) wrinkles. In tailored hot forming, in addition to these defects, (1) hardness or strength has to meet design requirements and (2) distortion may occur due to non-uniform phase transformations.

In the latest version of PAM-STAMP (2012), it is possible, with a blank, to (1) assign different thicknesses,(2) assign different material properties, and (3) model weld lines , as shown in Figure 5. Dies are automatically compensated for the extra thickness. All these features are compatible with hot forming simulations.

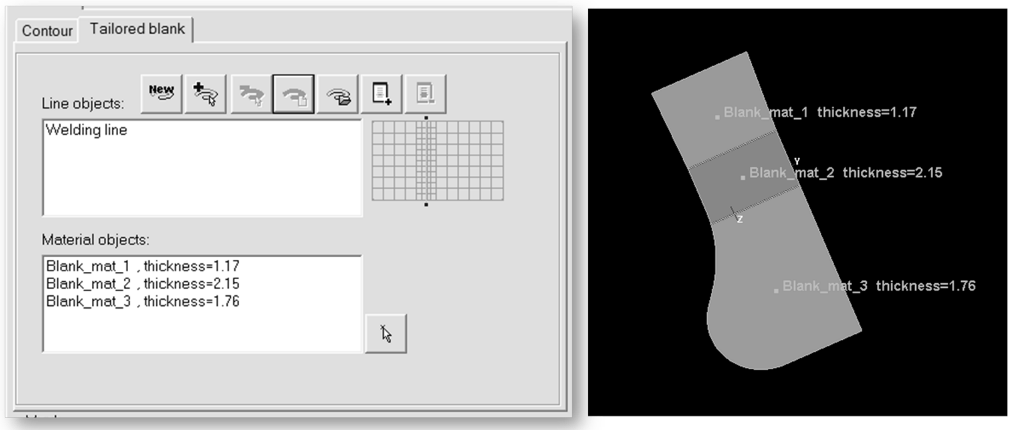
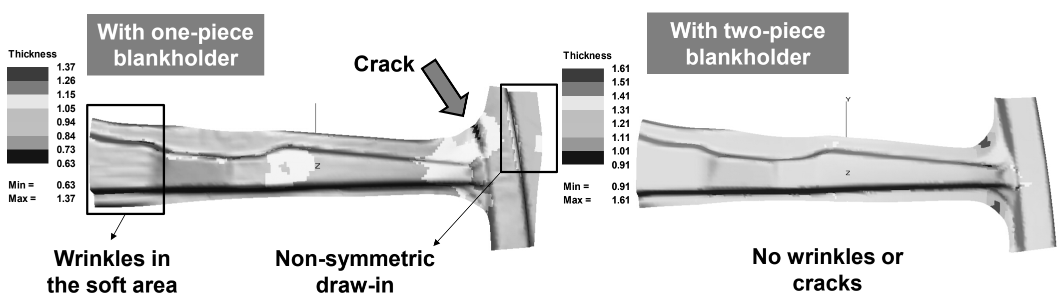


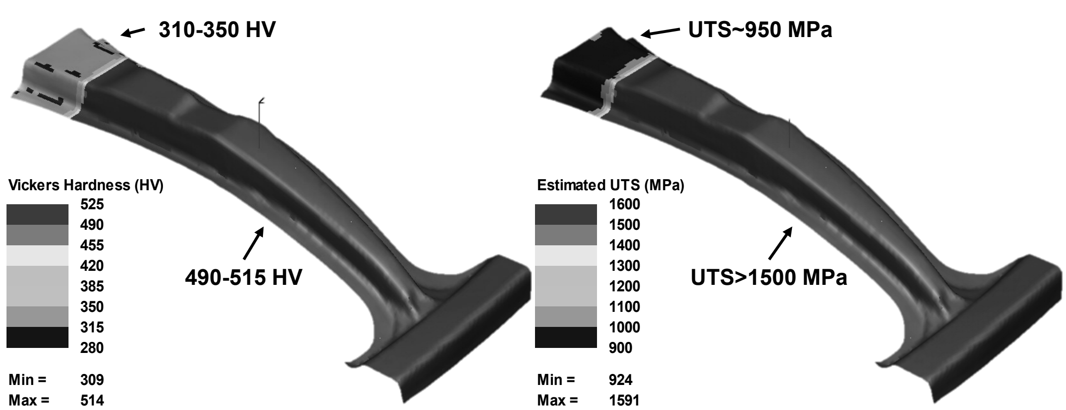
Figure 5: Modelling of Tailor Welded and Tailor Rolled Blanks in PAM-STAMP 2012.

As discussed earlier, hot forming adds a new, alternative method, in addition to TWB and TRB, to tailor the final part, by tailoring the microstructure. Process was designed based on Numisheet problem, and all the tools were divided into two assumed portions: heated zone (450°C) and cooled zone (20°C). By virtual try-out, it can be concluded that this part cannot be hot formed with a one-piece blankholder as the final part would have wrinkles in the soft-zone and cracks in the hard-zone. As seen in Figure 6, a two-piece blankholder was found to solve the problems and make a part without wrinkles or cracks.



(a) (b)

Figure 6: A tailored part simulation: (a) with one-piece blankholder, (b) with two-piece blankholder.



(a) (b)

Figure 7: Properties of the final part: (a) hardness and (b) estimated UTS distribution.

It is also possible to estimate the properties in tailored part, such as Hardness and UTS, without physically making the parts and performing the experiments (Figure 7). This helps the manufacturing engineer to optimize the process parameters (e.g., die temperature, press force at the bottom, quenching cycle time, etc.) for higher productivity and ensuring that the final properties are as required.

Summary and Conclusions

Regulations in safety and fuel efficiency are pushing the automotive industry to lightweight solutions more than ever. Tailored parts are one way to save weight, and TWBs have been used extensively in cold formed parts. Hot formed parts are increasingly used in the safety cages but face several challenges, including the lack of experienced engineers in process design and the need for tailored solutions to improve energy absorption characteristics.

Possible problems in mass production may be identified and solved by use of "Virtual Prototyping", which can save costly reworking of the dies and shorten the lead-time of the final product. With the advances in software engineering, it is now possible to control, adapt, and transport quantities between engineering disciplines. This is a key to concurrent engineering which helps to further reduce the overall cost.

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