Evaluation of Sheet Forming Simulation for an Integrated Reverse Engineering System

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ABSTRACT

This paper presents the method and results for the evaluation of sheet forming simulation software commercially available. The objective of the evaluation is to identify best suitable finite element-based simulation software for an integrated reverse engineering system that supports sheet metal forming at a defense logistics center. This system is composed of a set of software tools and hardware equipment that are seamlessly integrated to support in-house part manufacturing, from design to production. Excellent hardware equipment that supports reverse engineering and sheet forming manufacturing is currently employed at the center. The sheet forming simulation software is one of the major components being added to the system. This software evaluation is conducted entirely from the needs of the center. Simulation capabilities involved in the evaluation include relevant forming operations, such as draw, sheet hydro-forming and stretch forming; as well as die design, and blank nesting. Parts are physically formed in order to validate the accuracy of the simulation capabilities. Strength and shortfalls of the software evaluated are identified. The goal of the paper is to provide the technical community the current state-of-the-art in forming simulation technology and software tools that support practical applications.

Keywords: metal forming simulation, maintenance-repair-overhaul, aging systems.
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1 INTRODUCTION

Many weapon systems around the world were developed forty, even fifty years ago. Logistics centers face major challenges in maintaining weapon systems originally designed half a century ago — systems that are approaching, or have already reached the end of their intended service lives. The challenges stem from the premise that the existing systems designed using outdated technology simply cannot keep the weapon systems in service consistently. In addition, the original technical data packages, including engineering drawings, of the failed parts in weapon systems are either incomplete or completely missing [5]. The situation creates serious problems in either acquiring parts externally or conducting in-house manufacturing.

For some time, logistics centers have adopted various reverse engineering approaches that replicate original parts from physical samples. These approaches have provided some success in supporting logistics centers to accomplish its MRO (maintenance, repair, and overhaul) missions. In recent years, some logistics centers have attempted to accelerate the process by implementing an aggression of modern scanning devices with surface construction and solid modeling technology [6].

In manufacturing, some of the technology, process, and equipment, initially employed are out-of-date, and many vendors discontinue part supplies to logistics centers. In addition, to maintain aging systems of small quantities only small number of parts are often acquired by the logistics centers, which severely narrows the options of viable manufacturing methods and often leads to no-bid after a prolonged acquiring process.

With such a formidable challenge on the horizon — extending the service lives of aging systems — advanced computer-based design and manufacturing technology, unavailable half a century ago, provides logistics centers a great opportunity to confront and overcome the challenge. With the advancement in computer-aided technology, products and processes can be re-engineered for more durable and reliable alternatives, with faster and more cost-effective manufacturing options.

Several product and process re-engineering ideas were proposed to logistics centers. Among them is an integrated system that supports design and manufacturing for sheet metal forming. Such a system is being developed and implemented at a logistics center. In this paper, we focus on the evaluation of sheet forming simulation software, which is one of the major components of the integrated system. To facilitate the discussion, we will briefly introduce the integrated system in Section 2. In Section 3 we outline the technical approach taken to conduct the software evaluation and briefly discuss simulation capabilities involved in sheet metal forming. Strength and shortfalls of the current forming simulation technology and software tools are also identified. In Section 4, key observations made in parts that were simulated and physically formed are discussed. Conclusion of this study is given in Section 5.

2 THE INTEGRATED REVERSE ENGINEERING SYSTEM

The logistics center is currently employing various software tools and equipment for the design and manufacturing of sheet metal parts. These tools and equipment include scanners that capture part geometry for reverse engineering, software that supports constructing parametric solid models of the parts, production forming equipment, and CNC mills that machine the tools. Two previous studies respectively addressed two critical technical areas for part design and manufacturing; i.e., reverse engineering, and tooling and process selections for forming operations [1,6]. The tools, equipment, and manufacturing processes employed at the center are not yet integrated from a design view point. Furthermore, no forming simulations are available for engineers to design proper tooling and select an adequate forming operation, which considerably reduces the efficiency of reverse engineering and production of the needed parts. Software and equipment must be integrated, and missing technology must be acquired or developed and seamlessly integrated into the existing infrastructure at the logistics center.

An integrated system that supports design and manufacturing of sheet metal forming, as depicted in Fig. 1, is being developed. This system supports engineers to reverse engineer parts from physical samples, conduct forming simulation, select adequate forming operation, create die design, machine dies, and carry out sheet metal forming for part production. Overall, this system aims at streamlining design and manufacturing workflow, maximizing the benefits of the tools and equipment, improving productivity and supporting cost-effective productions at the logics center.

As shown in Fig. 1, the core of the integrated system is the sheet forming simulation. This simulation offers engineers the capability to assess the formability of the part design and the blank design. With the simulation, die design can be compensated by incorporating part spring back. In addition, adequate forming processes can be evaluated to determine best suitable process for support of part manufacturing. In this paper, we will discuss the evaluation of sheet forming simulation software, which is critical to the success of the integrated system.

3 EVALUATION ON FORMING SIMULATION SOFTWARE

The forming software evaluation involves survey (or initial screening) and hands-on evaluation. During the evaluation, we identify pros and cons of individual software based on criteria reflecting the needs of logistics center, such as spring back, blank design, availability of forming operations, ease of use, etc. The goal is to recommend the center best suitable software that meets the needs of the center.

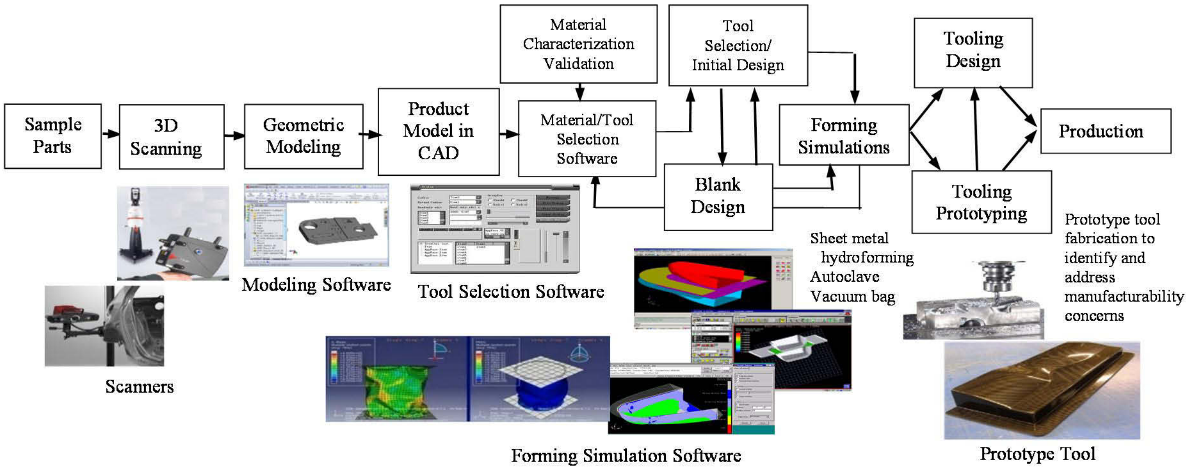


Fig. 1: Proposed integrated tool system for reverse engineering.

3.1 INITIAL SCREENING

The objective of the initial screening is to identify promising commercial forming software for hands-on evaluation. The approach taken was "on-paper" evaluation. An initial set of evaluation criteria in terms of availability of engineering capabilities at high level and costs of individual software tools was developed. A thorough software survey was conducted by reviewing information posted on software vendor's website, including product brochures, case studies, power point presentations, online demo, etc.

The initial screening led to the inclusion of eleven software tools for evaluation. They are FastForm, DynaForm, ABAQUS, LS-DYNA, AutoForm, Pam-Stamp 2G, QForm 3D, Deform, HyperForm, OpenForm, and Stampack. ABAQUS and LS-Dyna were filtered out for further evaluation since they are general-purposed FEA codes that are too broad to adequately support metal forming simulations, in addition to the steep learning curve. QForm 3D and Deform are inherently developed for simulating forming operations for metal blocks, such as forging, rolling and extrusion. OpenForm is more like a pre- and post-processors that are decoupled from particular finite element codes for forming simulation (although it also has its own FE solver named 'Indeed'). OpenForm supports major forming simulation software, such as AutoForm, LS-DYNA and PAM-STAMP. However, OpenForm does not have die design capability, which is the same drawback for STAMPACK. As a result, five software tools, FastForm, DynaForm, AutoForm, Pam-Stamp 2G, and HyperForm were selected for hands-on evaluation.

3.2 HANDS-ON EVALUATION

The hands-on evaluation involves two levels. In the first level evaluation, we focused on acquiring a general understanding on the overall engineering capabilities by going over tutorial examples provided by individual software tools. In the in-depth evaluation, we investigated individual forming capabilities that are needed to support shop floor practices at the logistics center.

3.2.1 First Level Evaluation

The objective of the first level evaluation is to identify two final candidates for in-depth evaluation. We requested and received on-line demos and/or trainings for all five software tools, went over tutorial examples for all software tools (except for AutoForm), collected and reviewed technical papers to better understand forming capabilities offered by individual tools, developing evaluation criteria, and analyzing pros and cons of the tools based on the established criteria.

The first level evaluation concludes with two software tools as the final candidates for in-depth evaluation. They are HyperForm and DynaForm. Both software tools offer good forming capabilities, including one-step analysis that supports engineers to check formability of the part using forming limit diagram (FLD) (example shown in Fig. 2), die design that incorporates addendum design and die compensation for spring back (example shown in Fig. 3), and excellent forming simulations using incremental analysis (example shown in Fig. 4).

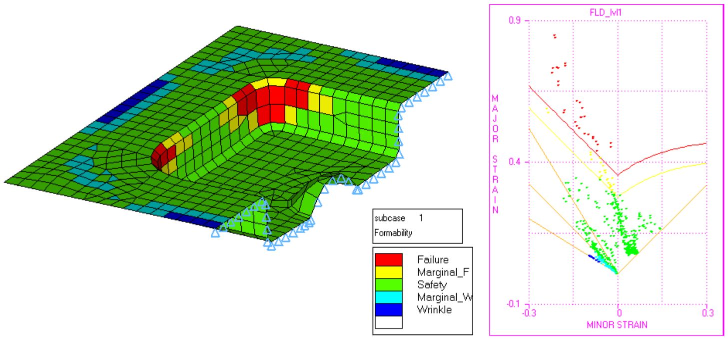


Fig. 2: One-step analysis results with forming limit diagram.

In addition to these critical capabilities, the key factor that led to the selection for HyperForm is its superior design capabilities. HyperForm supports draw bead design, optimization for one-step analysis, and die stress analysis and topology optimization. Optimization for one-step analysis allows users to move strain points closer to quality function curve by adjusting process variables, such as binder force, draw bead force, etc. Die stress analysis and topology optimization supports a light-weight tooling design by carrying out density-based topology optimization [4] using stress analysis results. One such example is shown in Fig. 5.

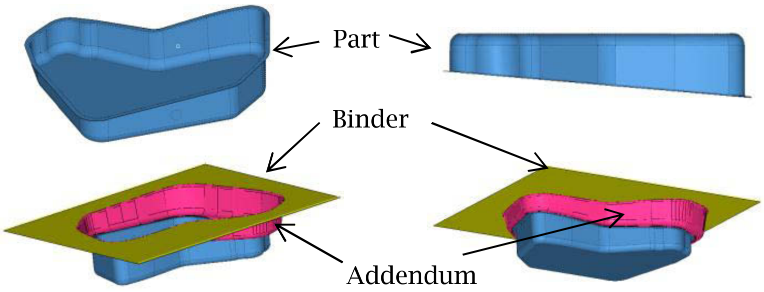


Fig. 3: Parametric addendum design for die.

On the other hand, the key factors that led to the selection for DynaForm is that it offers a fairly complete set of forming operations pertinent to the practices at the logistics center, intuitive user interface that would shorten the learning curve, and relatively less expensive among the five candidates.

Regarding the remaining three tools, Pam-Stamp 2G was not selected mainly due to its lack of blank fitting and blank nesting capabilities. FastForm does not support die design; it only provides limited materials and crude yielding criteria, and offers fewer forming operations. AutoForm does not offer trial license without having users attended the training course. There was too limited information offered during AutoForm demo to justify the inclusion of the software to the next evaluation.

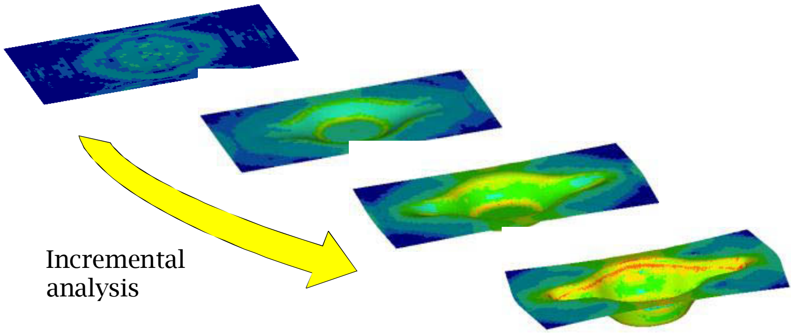


Fig. 4: Forming simulation: incremental analysis.

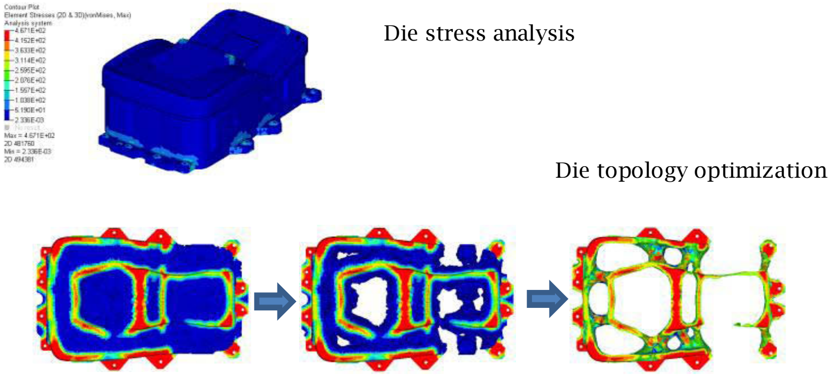


Fig. 5: Die stress analysis and topology optimization.

3.2.2 In-Depth Evaluation

The objective of the in-depth evaluation is to identify one forming simulation software that best suits for the needs of the logistics center. Several sample parts found in the literatures were used to carry out the evaluation. Some of the parts reported were physically formed, which offers references to verify the accuracy of the forming simulations. Among the sample parts, some are formed using sheet hydroforming, and the remaining using regular draw operation. In addition to the draw forming and sheet hydroforming, parts of relatively mild curvature were formed using stretch forming machines.

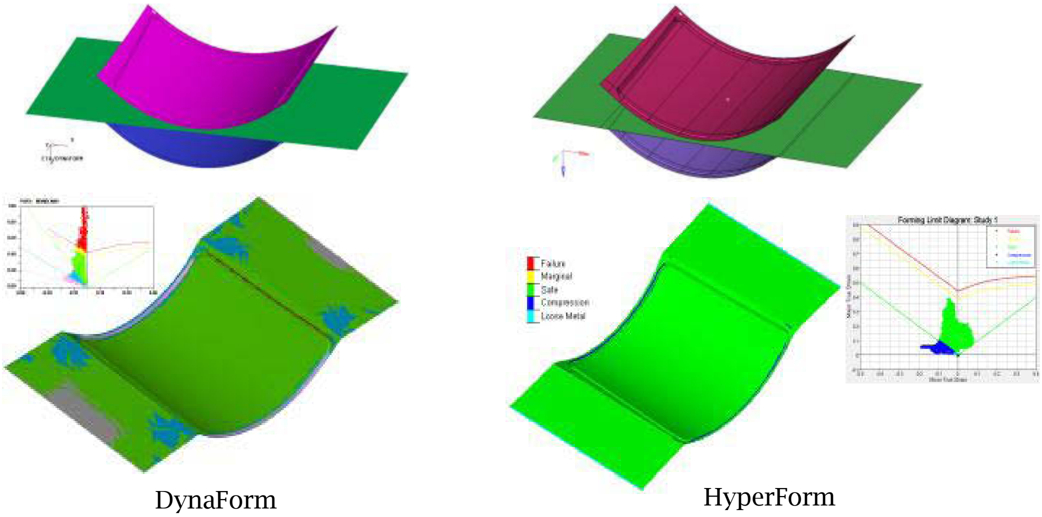
Both HyperForm and DynaForm perform well for regular draw forming. For example, sample part shown in Fig. 6 was simulated using both software with almost identical set up, including coordinate systems, tool surface, blank size, blank orientation, and blank location with respect to the tools. Finite element meshes created for the tools are different in HyperForm and DynaForm. Furthermore the underline element formulations are different. In addition, yielding criteria employed are Barlat and Hill [2,3,7] for DynaForm and HyperForm, respectively.

As shown in the forming limit diagrams in Fig. 6, both software tools predict similar results. Some tearing occurs around the draw beads (in red color), and small wrinkles (in light blue color) occur around the four corners on the outside of the actual formed part.

As for sheet hydroforming, DynaForm offers dedicated options for users to create and conduct forming simulation; for example, sample part shown in Fig. 7. Note that the simulation accurately predicted severe wrinkles outside the circular ring, which is apparent in the actual part (Fig. 7) formed by using a fluid cell. Also, stretch forming is well supported in DynaForm. Using DynaForm, the jaw can grip the edges of the sheet and form curves that deform the blank. The punch can then move upwards to deform the blank to a desired shape. If necessary, a female die can also be used to make the blank conform closer to the desired part shape, as illustrated in Fig. 8.

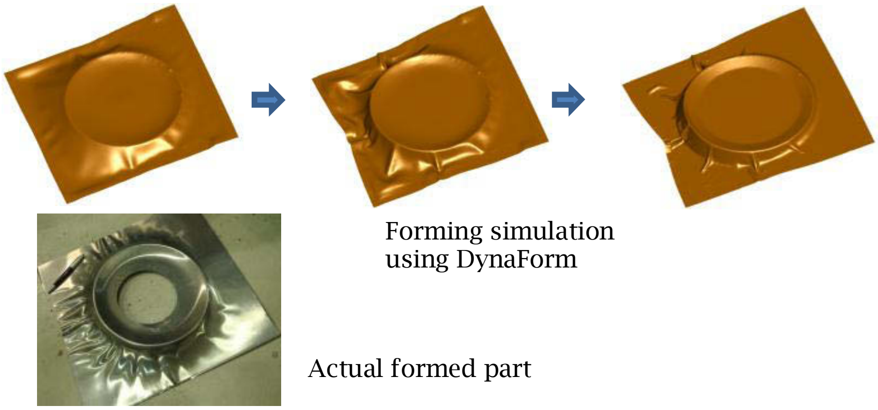
3.3 SOFTWARE COMPARISON

A set of criteria that was refined and extended from the first-level evaluation is used to support a quantitative measurement for the in-depth evaluation. A system that is similar to the calculation of grade point average was adopted for the quantitative measurement. Major criteria included in the measurement consist of geometry and meshing, materials, blank design, die design, one-step forming, forming processes, user interface, etc.



DynaForm HyperForm

Fig. 6: Forming simulations for sample part.



Forming simulation using DynaForm

Actual formed part

Fig. 7: Sheet hydroforming for sample part.

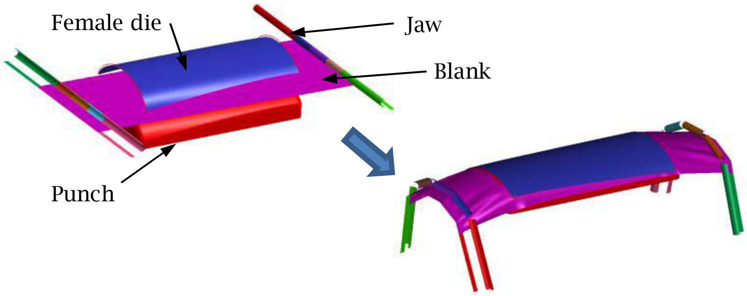


Fig. 8: Stretch forming simulation in DynaForm.

Portion of the criteria that are most relevant to the practices at the logistics center is collected in Tab. 1. As shown in Tab. 1, both HyperForm and DynaForm support blank design and draw forming well. DynaForm offers more material types, supports better yield criteria and more advanced hardening models. However, the most important is that DynaForm offers ready-to-use options for stretch forming and sheet hydroforming simulations. Whereas, HyperForm requires users to work outside the software and edit simulation input data files manually before running forming simulations. The work involved in such a manual editing is well beyond the ability of average users. Since two out of the three forming operations practiced at the logistics center are not well supported by HyperForm, DynaForm becomes the only viable option. The GPA calculated for HyperForm and DynaForm, based on the criteria listed in Tab. 1, are 2.4 and 3.8, respectively.

Criteria		Weighting	HyperForm	DynaForm	Comments
General	Tool control	5	B	A	DynaForm provides more options for: tool motion control, adding and deleting tools, tool contact, tool positioning, etc.
	Process parameters	5	B	A	DynaForm allows users to control: element formulation, No. of integration points, advanced friction coefficents, etc.
	Solver control	4	B	A	DynaForm allows users to control: time step size; advanced mesh adaptivity parameters; solver accuracy level, etc.
Material	Material library	2	C	A	HyperForm has much less materials in material library (no aluminum materials)
	Yield criteria	4	B	A	DynaForm supports more yield criteria (material models)
	Hardening models	3	D	A	DynaForm supports more hardening models when defining material stress-strain curve
Blank nesting and blank fitting	User interface	5	A	A	
	User flexibility	5	B	A	DynaForm provides more options for blank nesting
	Result output	5	A	A	Both software can output IGES files as result of blank fittingor nesting
Draw forming	User interface	5	B	A	DynaForm has more intuitive and straightforward user interface and is easier to use
	User flexibility	5	B	A	DynaForm provides advanced options throughout drawing simulation setup, including process parameters, tool control, etc.
Stretch forming	User interface	5	D	A	No existing user interface for stretch hydroforming in HyperForm
	User flexibility	5	D	A	DynaForm suports different kinds of stretch forming; tools can be generated based on machine parameters
Sheet hydroforming	User interface	5	D	B	No existing user interface for sheet hydroforming in HyperForm
	Rubber material	4	C	C	Both software do not support rubber material in existing material library
	Pressure definition	5	D	A	External text file editing required to create a pressure curve in HyperForm

Tab. 1: Portion of the criteria most relevant to the practices at the logistics center.

Overall, HyperForm offers excellent design capabilities and supports die topology optimization. However, as mentioned above, there is no ready-to-use option for stretch forming and sheet hydroforming in HyperForm; only basic simulation options are provided. On the other hand, DynaForm supports fairly complete set of forming applications, offers intuitive user interface and advanced simulation parameters. The weakness in DynaForm is that it offers less desired design capabilities; not as thorough as HyperForm.

4 OBSERVATIONS

Several important points are observed in carrying out the forming simulations for the sample parts. We will use two examples, a core panel shown in Fig. 9 and a skin panel shown in Fig. 14, to briefly illustrate these points.

The problem with the core panel is that the part reveals severe wrinkles around the corners of the concave pockets. This problem was first identified by the shop floor mechanists when the panel was physically formed. Simulations of three cases with binder force of 1, 10, and 100 tons (Cases 1, 2, and 3, respectively), were carried out. The results in Fig. 10 show that the wrinkles occur at the corner areas, as revealed in the physically formed part. In addition, the wrinkles reduce as the binder force increases. As we zoom in to take a closer look, for example, at one of the corner areas close to the center top of the panel shown in Fig. 11, it shows clearly that the strain points in two elements (A and B) gradually move out of the wrinkle area as the binder force increases.

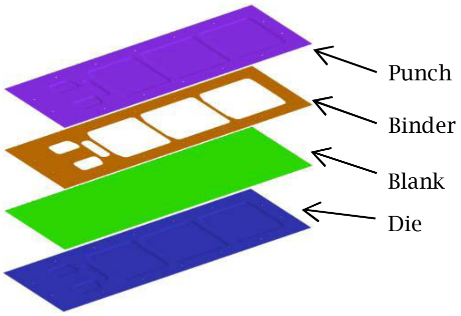


Fig. 9: Simulation set up for the core panel example.

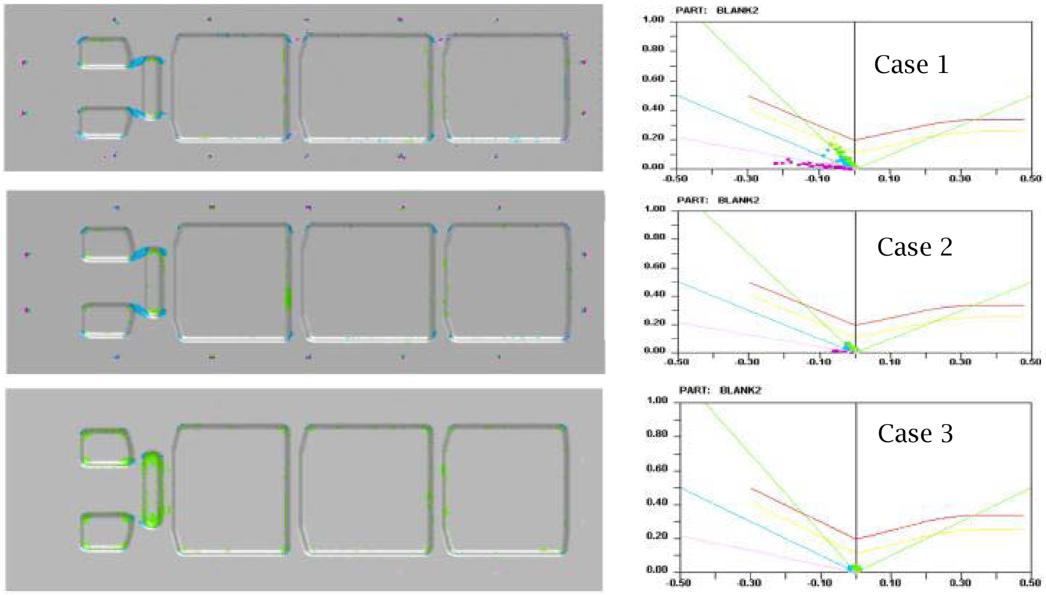


Fig. 10: Forming simulations for varying binder force.

The physics behind the results is straightforward. When the finder force is increased, the blank is held tighter; therefore, the blank material is more restrictive to move, especially around the corner areas where material tends to accumulate as it is being bent over to form the pockets. This phenomenon is confirmed with the thickness distribution, as shown in Fig. 12 around the same area. In addition, the displacement fringe plots shown in Fig. 13 indicate similar conclusions. As shown in Fig. 13, material movement is gradually reduced in both vertical and horizontal directions as the binder force increases, which reveal the basic cause contributing to the diminishing of wrinkles in the corner areas.

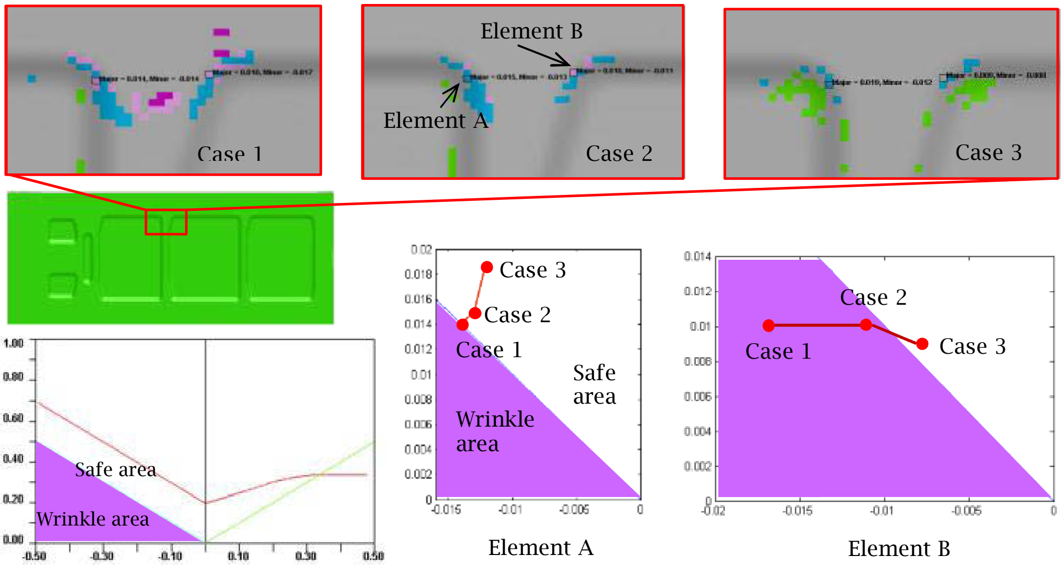


Fig. 11: Strain points move out of wrinkle area.

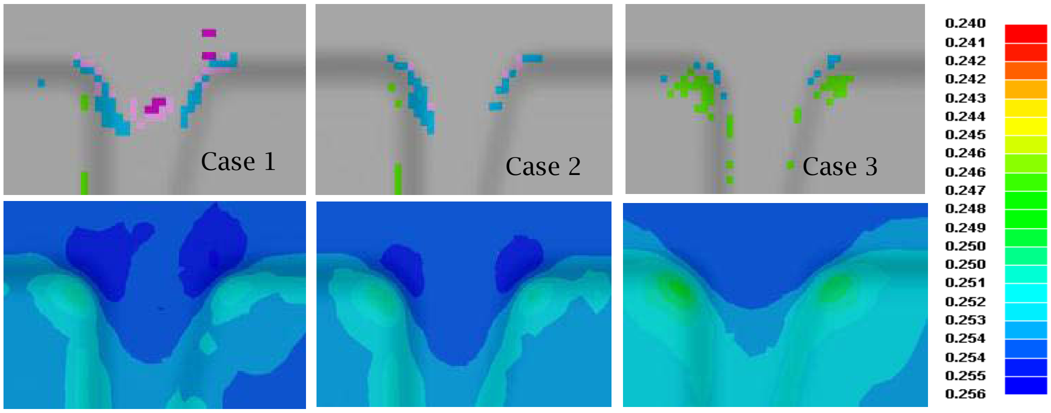
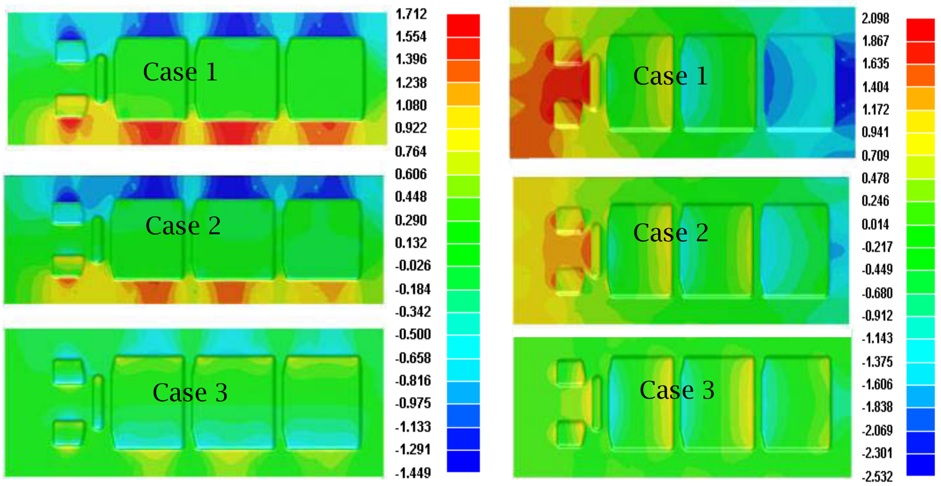


Fig. 12: Thickness distributions in all three cases.

In the second example shown in Fig. 14, sever tearing is encountered around the draw beads, which were created close to the four boundary edges of the punch and die. Simulation of three cases was carried out, each with varying blank size, as shown in Fig. 15. Case 1 of a small blank reveals most tearing as evident in the forming limit diagram. As shown in Cases 2 and 3, as the blank size increases, the tearing is gradually diminished.



Vertical displacement Horizontal displacement

Fig. 13: Displacement fringe plots.

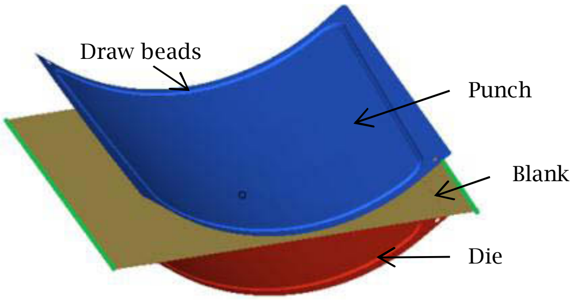


Fig. 14: Simulation set up for the skin panel example.

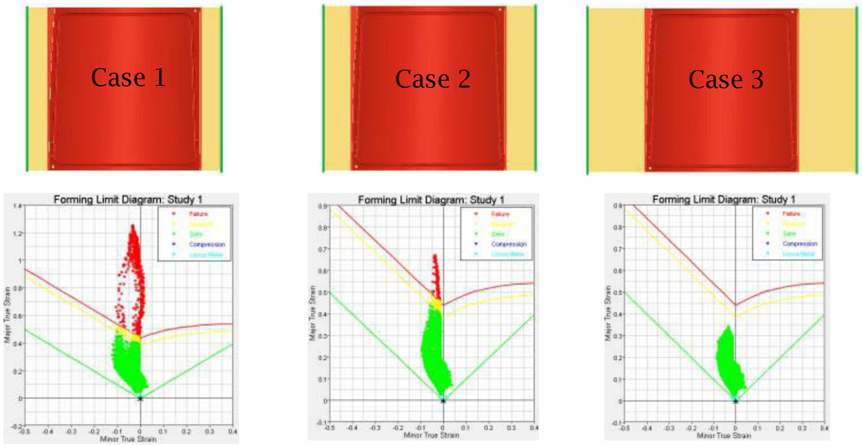


Fig. 15: Blank size and FLD of the three test cases.

The physics behind the results is again simple. When the blank size is increased, grips that hold the blank is farther away from the draw beads. As a result, the material is less restrictive to move, especially between the grips and draw beads; hence relieving the tearing around the draw beads.

5 CONCLUSIONS

In this paper, the method and results for the evaluation of sheet forming simulation software are presented. The best suitable forming simulation software for a defense logistics center has been identified based entirely on the criteria that reflect the needs of the center. In addition, the paper offers several important observations made in conducting simulations for sample parts found in literatures, including design approaches that would remedy problems such as wrinkle and tearing. Although during the evaluation, we developed evaluation criteria with objective measuring scheme, some of the grades we gave to the software tools are subjective, representing simply our understanding and viewpoint on the software tools.

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