Y/DV-1606

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Hydroforming Applications at Oak Ridge

E. L. Bird
Y-12 Development
Lockheed Martin Energy Systems, Inc.

and

G. M. Ludtka
Metals and Ceramics
Lockheed Martin Energy Research Corp.

For presentation at:

Society of Manufacturing Engineers
March 10 - 11, 1999
Livonia, Michigan

Prepared by the
Oak Ridge Y-12 Plant
Oak Ridge Tennessee 37831
managed by
Lockheed Martin Energy Systems, Inc.
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TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Hydroforming technology is a robust forming process that produces components with high precision and complexity. The goal of this paper is to present a brief description of the sheet hydroforming process with respect to the authors' experience and capabilities. Following the authors' discussion of the sheet-metal forming application, the tubular hydroforming process is described in the context of one of our technology development programs with an automotive industrial partner. After that is a summary of the tubular hydroforming advisor (expert system) development activity, which was a significant part of this overall program based on previous experience in developing a design and manufacturing support hydroforming advisor for the Oak Ridge Y-12 Plant's weapons-component manufacturing needs. Therefore, this paper is divided into three sections: (1) Hydroforming of Stainless Steel Parts, (2) Tubular Hydroforming, and (3) Components of a Tubular Hydroforming Advisor.

SECTION I — HYDROFORMING OF STAINLESS STEEL PARTS

To meet several unique design challenges related to weapons component production, hydroforming development activities began in Oak Ridge circa 1952 to investigate this very flexible process. Hydroforming is now a key process for our applications of forming stainless steel parts because near-net shaped parts of very high precision and varying complexity can be readily formed with excellent surface finishes. In addition, die costs are lowered because only the form die is needed for this process. Blanks used in the hydroforming process are sectioned from cold-rolled, low-carbon stainless steel, type 304L. Sheet metal hydroforming can be applied to a broad range of sizes, from very thin to 1 in. thick and from a 1 in. diameter to 32 in. Hydroforming is sometimes called fluid forming, flexible die forming, rubber diaphragm forming, or rubber pad forming.

Equipment: Four hydroform presses are available for manufacturing, depending on the size of the part being formed. A rubber wearpad protects the rubber diaphragm. Platen sizes range from 12 to 32 in., stroke distances range from 6 to 16 in., and pressures measure up to 30,000 pounds per square inch (psi). The newest hydroform press is computer controlled and has the ability to independently control pressure as a function of depth.

Process Description: In a typical scenario, the blank is lubricated in the region that rests against the draw ring and centered before forming. A precharge of ~1000 psi is applied to the blank, which cause deformation in the central region of the blank but, more importantly holds the ends of the blank down during the forming process. The punch containing the die is driven upward, pushing the blank against a rubber pad or diaphragm pressurized with fluid. Resistance, provided by the fluid-supported rubber pad, exerts pressure against the blank, thereby shaping the blank or workpiece around the die. An example of this process is shown in Fig. 1.

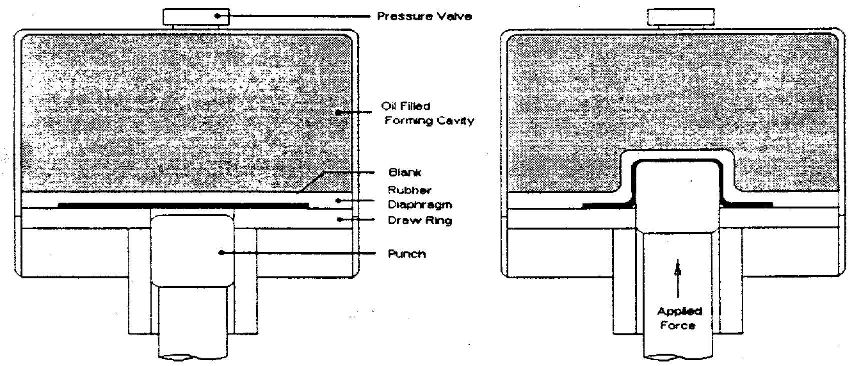

Fig. 1. Hydroforming process.

Key Processing Variables: Processing was primarily developed on a trial-and-error basis, and as a result, most of the process knowledge is based on experience. Key parameters known to affect the outcome of the desired shape include (1) lubricant, (2) blank size, (3) pressure, (4) punch speed, (5) depth of part, and (6) die radius. These conditions, some of which are interrelated, are controlled to prevent undesirable results such as wrinkling, tearing, buckling, and springback. The lubricant used for most applications is Houghton Draw 7007, which is sometimes thinned with solvent. Too much lubricant or application of the lubricant in the wrong place can lead to wrinkling or tearing. If the blank size or thickness is different, wrinkling can occur. Insufficient precharge pressure can lead to wrinkling. If the speed of the form die is too fast, wrinkling or tearing can occur. Typically, the radius of the die should not be greater than three times the thickness of the blank being formed. A larger bend radius often requires a wider flange, and formulas in the handbooks provide guidelines for whatever material is being formed. A cycle period (the time from closing the press until the part is stripped from the form punch) is typically only ten seconds. Tooling is usually made from H-13 tool steel, and the draw ring is usually made out of aluminum-silicon bronze. Other materials that have been hydroformed include copper, lead, titanium, nickel-based alloys, and aluminum.

SECTION II — TUBULAR HYDROFORMING

An example of a tubular hydroformed part will be presented first to help in understanding this variant of the hydroforming process. Fig. 2 shows a tubular hydroforming application in the automotive industry. This part is a major frame component that has many variable cross-section specifications along its length, as indicated in Fig. 3.

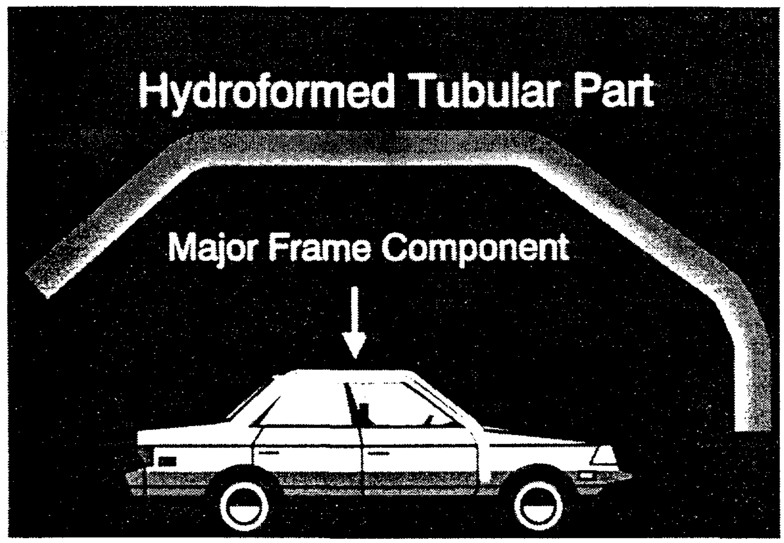

Fig. 2. A tubular hydroformed automobile frame component.

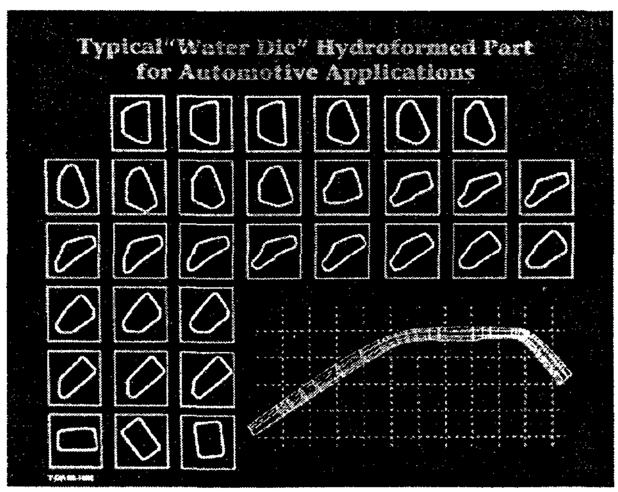

Fig. 3. Tubular hydroforming facilitates producing parts with a diverse range of cross sections along its length.

This automotive application, as shown in Figs. 2 and 3, highlights the benefits of tubular hydroforming over conventional forming. The following tabulation contrasts these two technologies to make the same part.

Traditional stamping of this car-body frame part requires the following:

1. Seven to nine steel dies at a cost of ~$300K to $500K;
2. several seam and spot welds;
3. time from blank to finish part, 1 to 10 days;

4. overall typical tolerance band, < 0.5 in. (plus part -to-part variance); and
5. material/part performance, hard to maintain.

Meanwhile, tubular hydroforming of this same shape would only require this:

1. Epoxy die set at a cost of ~$3K to $20K;
2. no seam welds and no spot welds required;
3. from blank to finished part time: 10 minutes;
   typically a two-step process of bending and then hydroforming)
4. overall typical tolerance band, < 0.1in.; and
5. material/part performance, improved rigidity and integrity
   (cuts weight and cost by using thinner material).

The materials generally used in this application have been seam-welded AKDQ (aluminum-killed, drawing quality) steel tubes. A successful implementation of this technology generally involves knowledge of the deformation behavior of the candidate materials. Therefore, the forming limit diagrams (FLD) for the candidate alloys need to be characterized so that the deformation limits of the material are known for consideration to a specific application. Because the tubular hydroforming process typically involves an initial bending step to meet the macroscopic geometry contour for the car frame shape (shown in Fig. 2), the FLD needs to be determined as a function of various amounts of prestrain. After the axial tensile prestrain step, the test tubes undergo the hydrostatic forming stresses that simulate the loading conditions that the tube will experience during the hydraulic forming stage that develops the many different cross-section contours (as seen in Fig. 3). Figure 4 presents an FLD that demonstrates the significant importance of knowing the influence that initial prestraining (such as in the bending operation) has on the final formability limits of the candidate material.

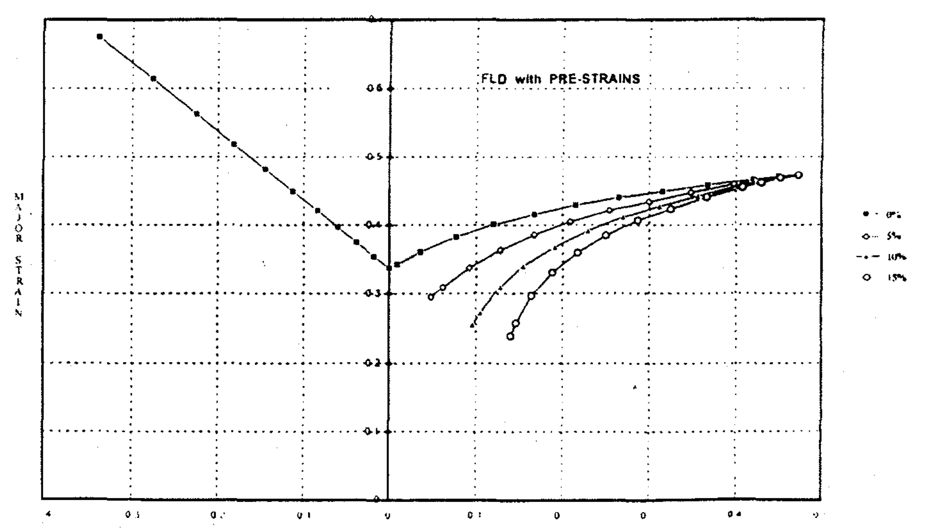

Fig. 4 Forming Limit Diagrams with Pre-Strains

Fig. 4. Generic FLD with prestrain effects shown.

As a result of working with an automotive partner in the tubular hydroforming area, the Y-12 Development Mechanical Testing Facility now has the fixtures and equipment to generate these types of data for tube products. FLDs have been generated on 4-, 3.5-, and 3-in. outer diameter tubes for different wall thicknesses for both ferrous and aluminum alloys. Typical test-tube lengths are ~26 to 32-in. long, and electro-etched grid circles (0.1-in. diam) over the entire specimen gage area were used to enable local strain measurements after failure.

Figure 5 shows another example of the use of tubular hydroforming technology in a rather sophisticated application; a sheet blank is seam welded into a tapered cylinder shape and hydroformed. The tooling used for this application is also shown in the figure.

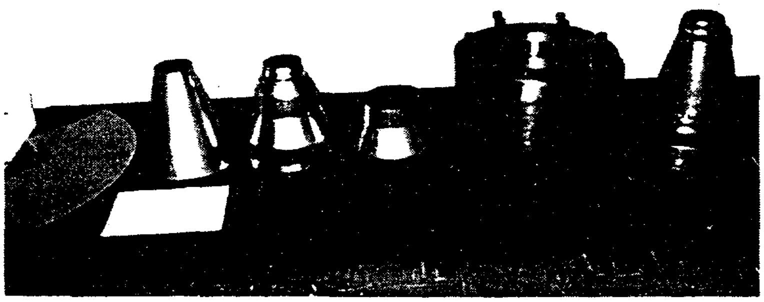

Fig. 5. This example of hydroforming technology shows the initial forming blank and the one set of tooling required to make the final part.

Over many years a significant amount of experience with hydroforming technology was developed within the Y-12 facility in designing tooling and understanding which applications were amenable to this forming approach and which were not. To record the knowledge and expertise in this area that several individuals gained over their entire careers, a manufacturing support program was initiated to develop a design advisor to capture this expert knowledge before those key individuals retired. Integrated with this information were appropriate material property databases along with other relevant features that will be discussed generically in the next section.

SECTION III — COMPONENTS OF A HYDROFORMING ADVISOR

When the Hydroforming Tool Die Design Advisor (HTDA) Program was initiated in 1989, its goals were to ensure that key individuals and experts in the hydroforming process could share their valuable information and expertise and to lessen the impact when these key personnel retired. The final tool that emerged could do the following:

1. capture and use expert knowledge required to best determine the compensation for hydroforming components (tool die, draw ring, etc.) used in the production of thin-walled parts;

2. use (captured) expert knowledge in the determination of optimal procedures, machine parameters, machine setups, etc., for making quality parts with low rejection rates; and
3. archive (electronically) past hydroforming data (both "graphical" and "non-graphical"). This capability is useful in the representation, analysis, and preservation of the Y-12 hydroforming knowledge base.

This internal effort was very successful and provided the experience base to develop a tubular hydroforming advisor for an automotive partner in a collaborative Research and Development Program. The three major components that made up the subsequent tubular hydroforming advisor, called the Hydroforming Design and Process Advisor (HDPA), are as follows:

1. combining models, high-power computing, and knowledge into an easy-to-use, (intelligent) human–machine interface with the analysis and "decision making " being "transparent" to the user;
2. integrating three information paradigms, namely, models, intelligence, and graphics (e.g., computer-aided design models) into a "seamless package"; and
3. integrating "process and design knowledge" with the total required decision-making paradigms, including information exchange and management, execution of "math models", and rule-based and other decision-making algorithms.

Using this philosophy and incorporating proprietary information from the industrial partner plus additional FLD data generated by Y-12 on ferrous-alloy and aluminum-alloy tubes, the HDPA emerged with the ability to do the following:

1. determine the appropriate tube-size range to generate the part shape that meets all boundary constraints;
2. determine the feasibility of the tube-bending step, generate the strain maps, evaluate the bending method, and predicts results;
3. analyze the tube-loading operations to provide early feedback on the tool-die contour, ensure continuity between the die and loaded pipe, and verify and analyze the proposed die geometries from the early steps; and
4. analyze the final predicted hydroformed part geometry and provide advisory reports on any suspected problem areas.

The four major analysis steps are (1) pipe diameter selection, (2) bend analysis, (3) die loading, and (4) hydroforming analysis. These steps were incorporated into a complete, easy-to-use graphic interface that can be used to input complete 3-D geometries and features. The highly interactive interface is useful during the initial stages of the complex hydroforming analysis cycle. The designer can easily access, change, or modify inputs as needed to address key design issues.

The benefit of the HDPA is that this advisor system determines the "manufacturability" early in the design cycle and provides a systematic knowledge/experience base that avoids making the same mistake twice. The advisor concept has proved to be a very useful paradigm for integrating knowledge, data, and graphics into an easy-to-use design and planning tool.

SUMMARY

This presentation has provided an introduction to the very robust hydroforming process and the experience and capabilities in Oak Ridge in applying this technology. For example, the tubular hydroforming variation of this process is extremely beneficial in meeting the manufacturability needs of an automotive frame component while requiring significantly less capital costs for tooling. Finally, the benefits of developing and using an advisor system for hydroforming include the integration of employee expert knowledge with other resources and tools to develop an easy-to-use design and planning tool.

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