O. Hydroform Materials and Lubricants Project

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Objective

- Develop mechanical test procedures and forming-limit diagrams for tubes.
- Improve the accuracy and confidence in finite element modeling of tubular hydroforming.
- Investigate the fabricating and performance characteristics of tailor-welded tubes.
- Develop an understanding of steel and lubricant requirements for hydroforming using a combination of experiments and finite element modeling.
- *Support the work of other Auto/Steel Partnership (A/SP) project teams when they investigate hydroformed structural components.*
- Validate the performance benefits of hydroforming in automotive structures.

Approach

The approach taken on this project is to gain a basic understanding of the hydroforming process and potential issues. The investigation encompasses various grades and gauges of steel tubing, including tailor-welded tubes, in free-expansion and corner-fill processes using several types of lubricants. The work has been divided into six phases.

1. Phase 1 – Free-expansion and corner-fill characteristics
2. Phase 2 - Effects of end feeding and pre-bending on hydroforming limits
3. Phase 3 - Investigate some of the pre-bending parameters for the hydroforming process
4. Phase 4 - Investigate some of the bending parameters for advanced high-strength steel tubing
5. Phase 5 - The experimental forming limits of steel tubes
6. Phase 6 - Empirical prediction of tube forming limit diagrams and analysis of hydroforming data

Delays in obtaining sheet stock and tubes caused Phases 3 and 4 to follow 5 and 6.

Accomplishments

During the report period (October 1, 2004 – September 30, 2005) the following were accomplished.

- Completed tube-bending tests comprehending two materials (IF and DP600), two bending speeds and two lubricants.
- Conducted inside and outside corner-fill tests on pre-bent DP 600 tubes.
- Conducted inside and outside corner-fill tests on pre-bent IF tubes.

Future Direction

During fiscal year 2006, the Hydroforming Materials and Lubricant plans to accomplish the following:

- Support the work performed by Lightweight Front End Structures (ASP080, see report 2.U) on a hydroformed front frame rail.
- Fabricate tailor-welded tubes for evaluation.
- Conduct free-expansion and straight-tube corner-fill tests on tailor-welded tubes.
- Begin to validate the performance benefits of tube hydroforming in automotive vehicle structures using tubes that simulate real-world applications.

Introduction

Hydroformed steel tubes have been used in the automotive industry to form components that meet structural objectives, particularly strength and rigidity, at optimal mass. One of the most significant advantages of tubes is that they are monolithic closed sections and, as such, exhibit many times more stiffness in torsion than conventional open sections, such as “C” and “hat” shapes. Their use is limited largely by a lack of knowledge about the capabilities and parameters of hydroforming processes and the effects of the processes on the tubes.

This project was undertaken to investigate and quantify the capabilities and parameters of various hydroforming processes so that automotive designers and engineers can utilize the tube configurations that are available and predict the performance of components made by hydroforming. Hydroforming tubes made from high-strength and advanced high-strength steels and fabricating and hydroforming tailor-welded tubes are of particular interest because of the potential reduction of mass associated with materials of higher strength and optimal thickness.

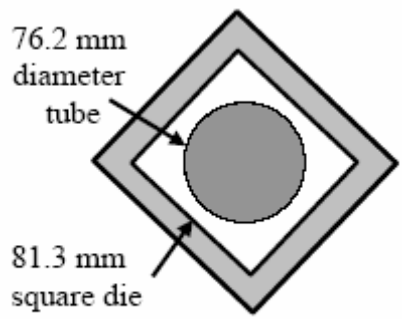
Discussion

Hydroforming is a process in which a tube is placed into a die, which is shaped to develop the desired configuration of the tube. Water is introduced into the tube under very high pressures, causing the tube to expand into the die. The tube ends can be held stationary or moved inward during the process to end-feed material into the die cavity.

The process has two distinct stages, shown in Figure 1. The first stage is free expansion (Figure 1a). It continues until the tube contacts the die wall (Figure 1b). In the second stage, corner filling, the tube is in contact with the surface of the die, which constrains subsequent deformation (Figure 1c). During this stage, the tube expands into the corners of the cavity, accomplishing corner fill. A tube that has been hydroformed is shown with the die in Figure 2. Note that the test was continued until the tube failed.

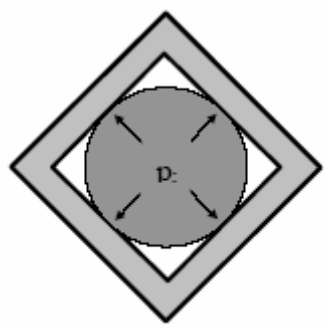
During corner fill, the tube slides against the die; therefore, friction between the tube and die affects the process, and the lubricant used in the process becomes a significant parameter.

During both stages, the tube undergoes plastic strain. The amount of plastic strain that can occur before the material fractures is predicted in stamping processes that utilize flat sheet steel by using a forming-limit diagram (FLD). The FLD is determined by the properties of the material. The hydroforming process is preceded by tube forming



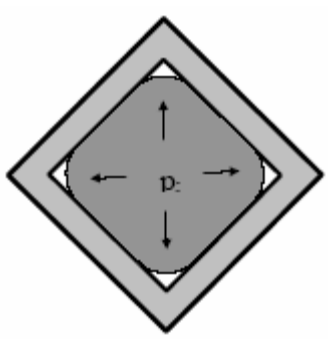
a) Free Expansion

Figure 1a



b) Contact with die wall

Figure 1b



c) Corner filling

Figure 1c

Figure 1. The Hydroforming Process

and sometimes pre-bending of the tube, both of which induce strains in the material and alter its properties. Before an FLD can be developed for the hydroforming process, the strain history, that is, the strain induced in the material prior to hydroforming, must be known.

An FLD is required for any successful computer simulation of hydroforming. Therefore, in addition to experiments with tube expansion to determine the effects of axial compression and tension in combination with internal pressurization, the effects of pre-bending and pre-forming on subsequent formability was addressed. Collected data were used to develop forming-limit diagrams for tubular hydroforming of straight tubes. These data will be used to develop guidelines for optimizing bending operations.

Figure 2. A hydroformed tube and die

Presently, the formability limits for pre-bent steel in tubular hydroforming are poorly understood. Accuracy needs to be addressed and improved to allow optimum application of tubular hydroforming in the lightweighting of vehicles.

Tube bending-phases 3 and 4, which were delayed while obtaining the selected sheet steel and converting to tube, began in November, 2004. The bending tests comprehend three variables: material, lubricant and bending speed. The materials are interstitial free (IF) and dual-phase (DP600); a water-based and a mineral oil-based lubricant were selected. Bending speeds were selected. The results will be evaluated to determine the effects of these variables on tube surface quality and hydroforming formability.

The Hydroforming Materials and Lubricants Project Team have begun to evaluate the potential of tailor-welded tubes for the hydroforming process. This phase of testing will be conducted on 76.2-mm (3”)-OD tubes made from two material grades and two thicknesses. The test will consist of five iterations as follows:

1. Baseline: 1.5 mm DP600 single material tube (20.00 inches long)
2. 1.5 mm DP600 butt-welded to 1.5 mm DP600
3. 1.2 mm DP600 butt-welded to 1.5 mm DP600
4. 1.5 mm HSLA350 butt-welded to 1.5 mm DP600
5. 1.5 mm HSLA350 butt-welded to 1.2 mm DP600

The tubes will be analyzed and then utilized for hydroforming tests.

Requests for quotation have been sent to two tube fabricators and one has been selected. A request for Purchase Order has been issued and is currently being processed.

Future Work

During the 2006 fiscal year, the Hydroforming Materials and Lubricants Team plan the following work:

1. Procure the five sets of tubes for the tailor-welded tube evaluation.
2. Analyze the tubes.
3. Perform hydroforming tests.
4. Continue to support the work of ASP080 Lightweight Front End Structures.
5. Validate the performance benefits of tube hydroforming in automotive vehicle structures.

Conclusions

Analysis of tests run during this reporting period indicates that:

- Bending speed had no measurable effect on the inside bend geometry and strain patterns for both the DP600 and IF tubes. The speeds evaluated were 22.5°/ sec and 30°/sec (4 sec. and 3 sec. to bend 90°) for DP600 tubes and 22.5° /sec. and 36°/sec. (4 sec. and 2.5 sec. to bend 90°) for IF tubes.
- Lubricant choice had a measurable effect on both bending and corner-fill hydroforming.