F. Hydroform Materials and Lubricants Project

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Objectives

- Develop mechanical test procedures and forming limit diagrams (FLDs) for tubes.
- Improve the accuracy and confidence in finite-element modeling of tubular hydroforming.
- Develop an understanding of steel and lubricant requirements for hydroforming using a combination of experiments and finite-element modeling.

Approach

- Determine the forming limits of various grades and gauges of steel tubing in free expansion and corner fill processes using several types of lubricant to provide (FLDs) for each set of parameters. The work has been divided into six phases:
  Phase 1—Free expansion and corner fill characteristics
  Phase 2—Effects of end feeding and prebending on hydroforming limits
  Phase 3—Optimizing prebending parameters for the hydroforming process
  Phase 4—Optimizing bending parameters for advanced high-strength steel tubing
  Phase 5—The experimental forming limits of steel tubes
  Phase 6—Empirical prediction of tube FLDs and analysis of hydroforming data

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

Accomplishments

- Evaluated the validity of the traditional forming limit curve for sheet metal stamping as it relates to tubing.
- Developed forming limit correction factors for tubular hydroforming of straight tubes.
- Developed forming limit curves for tubular hydroforming of straight tubes.
- Modified compression test tooling and prepared test samples to permit tension as well as compression of tubing during pressurization, allowing us to collect data for both sides (draw and stretch-form) of the FLD for quasi-linear strain paths for 0.79 IF-GA, 0.79 AKDQ, and 0.79 DP 600 steel tubes.

- Completed and published on the Auto/Steel Partnership (A/SP) Web site a summary report of Phases 5 and 6, performed at the Industrial Research and Development Institute (IRDI).

Future Direction

- Complete Phases 3 and 4.
- Evaluate tailor-welded tubes in free expansion and corner fill processes to determine the integrity of the laser welds under internal pressurization.

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 of hydroforming processes and the effects of the processes on the tubes.

This project was undertaken to investigate and quantify the capabilities and effects 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 is of particular interest because of the potential reduction of mass associated with materials of higher strength.

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 during the process to induce either compression or tension.

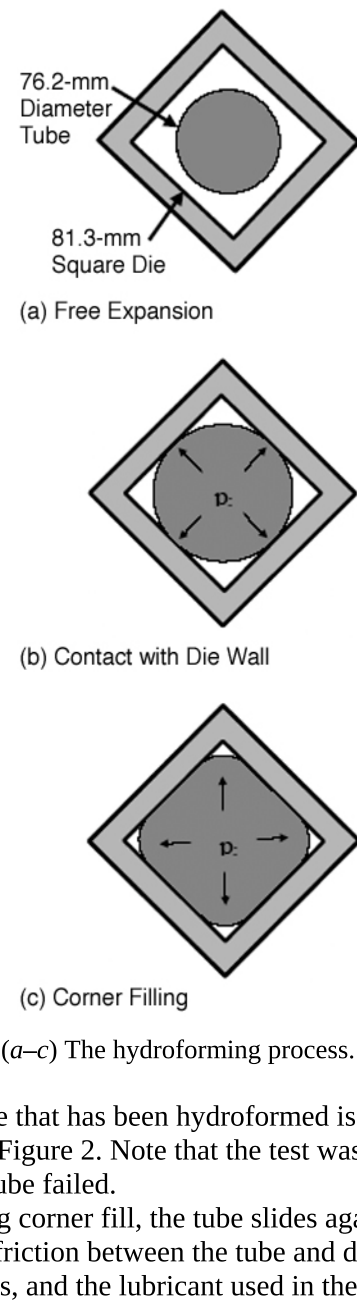

Figure 1. (*a–c*) The hydroforming process.

The process has two distinct stages, shown in Figure 1. The first stage is free expansion, [Figure 1(*a*)]. It continues until the tube contacts the die wall [Figure 1(*b*)]. In the second stage, corner filling, the tube is in contact with the surface of the die, which constrains subsequent deformation [Figure 1(*c*)]. 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.

Figure 2. A hydroformed tube and die.

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 and sometimes prebending 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 prebending and preforming on subsequent formability were addressed. Collected data were used to develop FLDs for tubular hydroforming of straight tubes. These data will be used to develop guidelines for optimizing bending operations.

Presently, the formability limit for prebent steel in tubular hydroforming is poorly understood. The effect of prior strain induced in the tube conversion and tube bending processes that precede the hydroforming operation has been ignored. Accuracy needs to be assessed and improved to allow optimum application of tubular hydroforming in the lightweighting of vehicles.

Future Work

Tube bending, phases 3 and 4, which were delayed while obtaining the selected sheet steel and converting to tube, will begin 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 have been selected. Bending speeds have not yet been finalized. The results will be evaluated to determine the effects of these variables on tube surface quality and hydroforming formability. Bending services have been procured to perform this phase of the work.

The Hydroforming Materials and Lubricants Project Team is considering a proposal to evaluate the potential of tailor-welded tubes for the hydroforming process. Structural members fabricated from this type of tubing have the potential for mass reduction and improved crash energy absorption. The Team has tentatively selected two grades and thicknesses of steel that are representative of those that will be used in forthcoming applications and are currently available.

Conclusions

Analysis of tests run to date indicates the following:

- Tensile testing in the longitudinal direction is sufficient to adequately characterize the mechanical properties of tubes having a diameter of 76 mm or larger.
- Free expansion tests helped to determine stress and strain behavior as well as formability limits for tubes pressurized in free space.
- Limit strains for low carbon steel tubes can be predicted from the tube mechanical properties.
- Free expansion tests of bent tubes highlighted the existence of an area along the bending neutral axis in which deformation tends to localize when the bent tube is pressurized.
- Material formability has much more influence on the expansion into a corner than friction or end feed conditions. However, friction has a

very significant influence on thickness uniformity in the wall of the hydroformed part.

- Different benchmark tests were also carried out to determine tube behavior under internal pressure.