Journal of Manufacturing Processes 15 (2013) 256–262

Contents lists available at SciVerse ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Technical paper

Failure analysis of hydroforming of sandwich panels

Jyhwen Wang[a,b,*], Cheng-Kang Yang[b]

[a] Department of Engineering Technology and Industrial Distribution, Texas A&M University, College Station, TX, USA
[b] Department of Mechanical Engineering, Texas A&M University, College Station, TX, USA

ARTICLE INFO

Article history:
Received 4 September 2012
Received in revised form 17 January 2013
Accepted 29 January 2013
Available online 17 March 2013

Keywords:
Hydroforming
Sandwich panels
Failure analysis

ABSTRACT

Sandwich panels are commonly used in various applications to improve the stiffness-to-weight ratio of structure components. While producing flat sandwich panel is relatively straightforward, manufacturing of shaped sandwich components can be a challenging task. This paper presents the use of hydroforming technique in forming bi-layered and sandwich materials with an open-cell foam core. Hydraulic bulge experiments were conducted to form bi-layered and sandwich blanks into a dome shape. Various failure modes were observed from the experiments. Finite element simulations were conducted to understand the different failure mechanisms that could occur during the deformation process. The investigation can facilitate the selection of geometry and property of the constituents of the sandwich material for successful hydroforming.

1. Introduction

Light-weight sandwich panels are commonly used in various industries to improve the stiffness and reduce the weight of structure components. In aviation and aerospace industry, sandwich panels are widely adopted in body and airfoil design of the aircraft to obtain a better stiffness to weight ratio. In automotive industrial, sandwich panels are designed as shock-absorbing and impact-resistant materials in racing car. These sandwich panels generally consist of metal face sheets, such as steel or aluminum sheets, and a porous light-weight core, such as a honeycomb or metal/polymer foams.

While producing flat sandwich panels is relatively simple, manufacturing of shaped sandwich panel can be costly and time consuming. The face sheets are formed in a stamping press first. The shaped core is then produced from expensive machining or molding process. Finally, an adhesive bonding operation is required to assemble the face sheets and the core.

An alternative to the traditional approach is to produce flat sandwich panels first and then forms the panels into the desired shapes. The approach, however, generally results in the collapse of foam core. Elzey and Wadley [1] analyzed the open die forging of structural sandwich with porous core. It was shown that the deformation process can lead to a non-uniform core density and thickness distribution (indication of core collapse). Mohr [2] conducted deep drawing experiments using thin sandwich blanks with metal face sheets and perforated sheet metal core. The experimental results showed that, due to bending, the dominant failure mechanism is core shear. From numerical analysis, it was also found that the required core shear strength is proportional to the face sheet strength. Jackson et al. [3] conducted experiments in incremental forming of sandwich panels. With the loading from the forming tool, the soft core was non-uniformly deformed. From the previous work, it can be observed that while forming sandwich panels, the high contact force between the tool/die and the sandwich blank generally results in crushing or fracture of the lower strength core material.

In order to prevent damage of the open cell foam core while forming shaped sandwich panels, sheet hydroforming technique can be considered. In the automotive industry, sheet hydroforming process is used to produce components with complicated shapes that are difficult to form using traditional stamping processes. In sheet hydroforming, the hydraulic fluid can uniformly exert pressure on the workpiece surface. The technique could reduce tooling contact, avoid excessive localized deformation, reduce springback, and improve the part strength. Sheet hydroforming has been widely studied. Hill developed an analytical model to describe the deformation of the metal sheet in a bulge test [4]. Chakrabraty et al. improved Hill's work by including hardening coefficient. The effects of work hardening on the thickness and the dome height are also investigated [5]. Shang et al. developed a model to predict the influence of the die radius on sheet hydroforming [6]. They also found that allowing draw-in of the flange can improve the formability of the sheet metal [7]. Hein et al. presented the forming mechanisms at different areas in free hydroforming of a single blank [8]. Controlling the blank holder force to improve the formability of the sheet was reported by Shulkin et al. [9]. A comprehensive

* Corresponding author at: Department of Engineering Technology and Industrial Distribution, Texas A&M University, College Station, TX, USA. Tel.: +1 979 845 4903.
E-mail address: jwang@tamu.edu (J. Wang).

1526-6125/$ – see front matter
http://dx.doi.org/10.1016/j.jmapro.2013.01.008

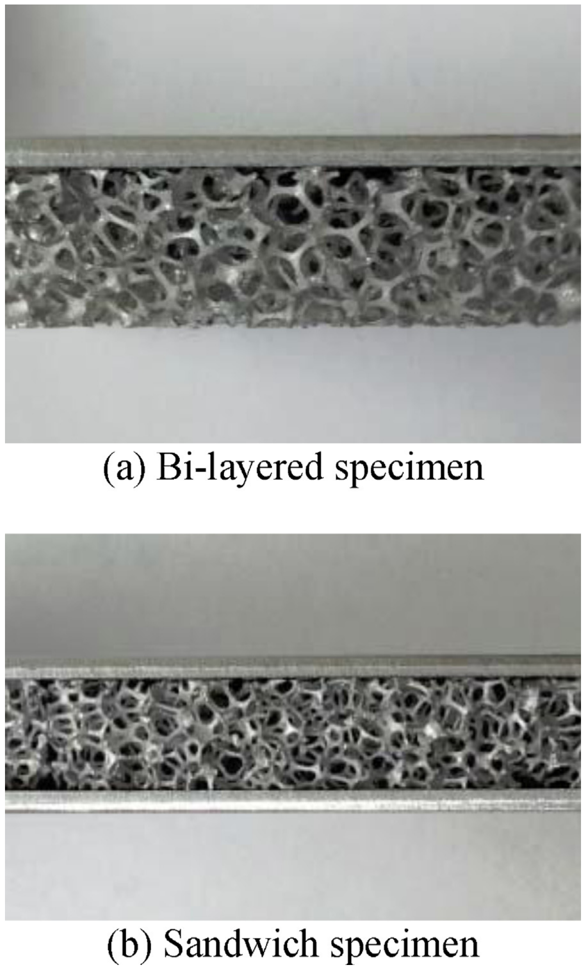

Fig. 1. Specimens for hydroforming experiments. (a) Bi-layered specimen and (b) sandwich specimen.

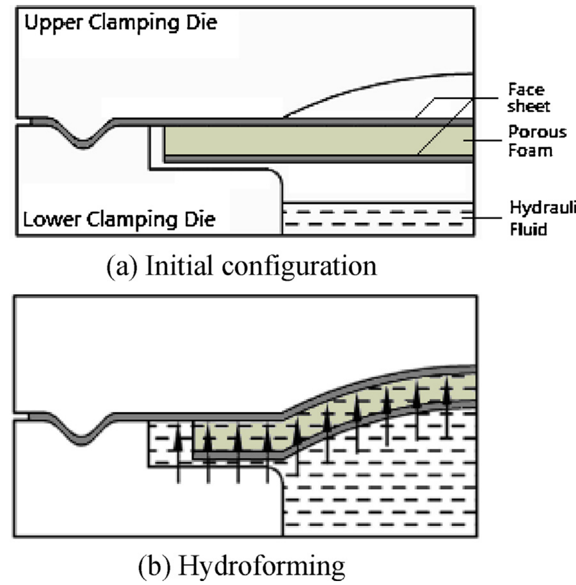

Fig. 2. Hydroforming of a sandwich panel (a stretch forming process). (a) Initial configuration and (b) hydroforming.

review of sheet hydroformig processes can be found in [10] by Vollertsen.

In the present work, the feasibility of using sheet hydroforming techniques to form bi-layered and sandwich panels is demonstrated. The process is similar to the bulge forming test [11] that is used to test the biaxial formability of sheet metal. A porous material, such as a metallic or polymer foam, can be attached to a sheet metal to form a bi-layered panel. An additional bottom face sheet can be attached to the other side of the porous material to make a sandwich panel. With different specimens and deformation conditions, various failure modes were observed. The experimental results can be explained by the results obtained from numerical (finite element) simulations, and a better understanding of the failure mechanism is achieved.

2. Hydroforming experiments

To produce shaped panels, bi-layered blanks (Fig. 1a) and sandwich blanks (Fig. 1b) with open-cell foam core are used in the hydroforming experiments. The premise is that during the forming process, the hydraulic fluid is allowed to flood the pore of the open-cell foam without collapsing the foam core. Fig. 2 depicted the process. Fig. 2a showed that the upper face sheet was first clamped. Then the hydraulic fluid can fill the sealed chamber without damaging the foam core. In Fig. 2b, with continuous increase of the hydraulic pressure, the upper face sheet can be deformed. And due to the adhesive bond, the core material and the bottom sheet could be formed into the upper die cavity.

2.1. Specimen preparation and experimental setup

Both bi-layered and sandwich panels were prepared for hydroforming experiments. Aluminum 5052 sheet with a thickness of 0.5 mm was used as face sheets. The diameter of the top face sheet was 241.3 mm, and the bottom face sheet of the sandwich panels had a diameter of 152.4 mm. The extra surface area of the upper face sheet is used for clamping such that the lower chamber (containing hydroforming fluid) can be sealed. The core material was prepared from Duocel open-cell foam blocks with 40 pores per 25.4 mm. The foam blank thickness was 6.35 mm. The primary material of Duocel foam was 6101-T6 aluminum alloy, and the relative density ratio was 8%. Since the bi-layered and sandwich panels are to be subjected to stretch forming, polyurethane adhesive was used to provide good flexibility. The bonding strength between the face sheet and the foam depends on the surface preparation. To produce blanks with different bonding strength, some of the face sheets were roughed by sand paper and were cleaned by using acetone.

The specimens were placed between a clamping plate and hydroforming die with an opening of 177.8 mm. During an experiment, the hydraulic pressure was slowly increased and the bulge forming process was stopped at a preset pressure or when a sharp pressure drop was detected. The specimen was then inspected for any failure.

2.2. Experimental results

From the experiments, it was observed that limited deformation was achieved in bulge forming of sandwich blanks. The bi-layered panel, on the other hand, can be deformed into a deeper dome shape. That is, while the top face sheet was stretched, the foam blank was "pulled" and deformed with the face sheet. During hydroforming, the fluid can flow into the porous open cell foam core. Thus, no foam damage (collapsing of foam core) was observed. The failures in forming the bi-layered and sandwich specimens can be classified into three categories.

The first type of failure is top face sheet fracture. It can be detected from a sudden pressure drop. The fracture location can