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International Journal of Solids and Structures 42 (2005) 1491–1512

INTERNATIONAL JOURNAL OF SOLIDS and STRUCTURES

www.elsevier.com/locate/ijsolstr

On the role of shear strength in sandwich sheet forming

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Received 12 May 2004; received in revised form 16 July 2004
Available online 18 September 2004

Abstract

This paper deals with the design of thin, all-metal sandwich sheets for forming applications. Draw bending experiments have been performed on thin prototype sandwich materials with metallic cores of 10% relative density. The experimental results reveal core shear failure as the dominant failure mechanism. Detailed finite element analysis has been carried out to gain further insight in the mechanics of bending and unbending of sandwich sheets. Based on theoretical analysis, design maps have been constructed describing the required core shear strength as a function of the face sheet properties as well as the sandwich core thickness and the draw radius. Furthermore, the relationship between shear strength and relative density has been determined for perforated sandwich core materials. The main result of this study is that the shear strength of formable sandwich sheets should be at least one order of magnitude higher than that of most commercial cellular solids. Here, perforated sandwich cores of relative densities above 25% are suggested to prevent sandwich sheets from core shear failure in forming operations.

Keywords: Sandwich sheets; Formability; Shear strength; Cellular solids; Perforated core sandwich sheets (PCSS)

1. Introduction

Structural weight reduction is still one of the prime design objectives in automotive engineering. Various concepts have been recently proposed to enhance the weight specific performance of modern passenger cars. Among those, weight advantages are expected from the use of sandwich sheet materials, which comprise two face sheets and a low-density core material. Sandwich panels have already proven their superiority in aerospace applications. However, different from aircraft structures, the body-in-white of a passenger

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0020-7683/$ - see front matter
doi:10.1016/j.ijsolstr.2004.07.012

car is typically manufactured by converting flat blanks into complex three-dimensional shapes using various sheet metal forming operations. Thus, for the success of a new sandwich sheet material in the automotive industry, it is advantageous to design flat sandwich sheets such that traditional sheet metal forming technology can be used.

Not much is known on the formability of sandwich sheet materials. Large sandwich structures are typically manufactured by forming the sandwich face sheets and core separately before bonding the face sheets to the core. Some work has been published on the forming of so-called light-weight laminates, where thin metallic face sheets (about 0.2 mm) are separated by a 0.8 mm thick polymer core (e.g. Pearce, 1991). However, as sandwich sheets with polymer cores cannot be welded, their potential use in automotive applications is mostly limited to the secondary components of the car body (Porsche Engineering Services Inc., 1998). All-metal sandwich materials of a total thickness of about 1 to 2 mm are still under development. Gustafsson (2000) proposed the Hybrid Stainless Steel Assembly (HSSA) with a stainless steel fiber core as new material for future vehicles. Another novel sandwich sheet material has been recently presented by Markaki and Clyne (2003). Different from Gustafsson's material, where the single fibers are aligned perpendicularly to the face sheets, Markaki and Clyne arrange the stainless steel fibers in a network with solid joints between contacting fibers, thereby increasing the shear stiffness and strength of the fiber core material. However, one important question regarding sandwich core design remains to be answered: how strong do sandwich cores have to be in order to sustain shear loads throughout forming operations?

This paper deals with the core shear strength required to successfully form a flat sandwich sheet into a two-dimensional shaped structure. The focus of this study is to investigate the forming of a U-shaped part by draw bending of an initially flat sandwich sheet. This simple sheet metal forming operation is studied because it isolates sandwich failure due to shear loading from other sandwich failure modes such as wrinkling or necking. Forming experiments are performed on sandwich sheet prototypes composed of a fiber core sandwich sheet as well as a perforated core. A detailed numerical and theoretical analysis of the bending and unbending of the sandwich sheet follows. This yields an explicit expression for the required sandwich core shear strength as a function of the face sheet properties, core thickness, and bending radius. A case study is carried out to design a perforated core such that it withstands the shear loads during draw bending. The results reveal that metallic sandwich sheets with high-density cellular core materials must be developed in order to prevent core shear failure in standard forming operations.

2. Experiments

Draw bending experiments are performed to gain some insight in the formability of sandwich sheets. Thin metallic sandwich sheets of a total thickness of about 1 mm are not yet commercially available and are still under development (Gustafsson, 2000; Markaki and Clyne, 2003). Therefore, prototype sandwich sheets are used in this experimental study.

2.1. Prototype sandwich sheet materials

We limit our attention to the following two prototype sandwich sheet materials:

- *Fiber core sandwich sheet (FCSS) material*: This novel type of sandwich sheet material has been provided to us by the Gordon Laboratory at Cambridge University. Two 0.2 mm thick austenitic stainless steel 316L face sheets are separated by a core of about 0.8 mm thickness (Fig. 1). The fibrous core is made of melt-spun ferritic stainless steel MO446 fibers which are brazed to the face sheets using a Ni–Cr based