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Paper Honeycomb Sandwich Panels as Lightweight Structural Components

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Paper Honeycomb Sandwich Panels as Lightweight Structural Components

T. W. Reichard

Building Research Division
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

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Contents

	Page
1. Introduction	1
2. Honeycomb Cores	3
3. Facings	5
4. Adhesive Bonding	5
5. Summary	5

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Paper Honeycomb Sandwich Panels as Lightweight Structural Components

T. W. Reichard

This paper presents a resumé of current practice in the U.S. with regard to the use of sandwich panels in single-story buildings. Descriptions and properties of typical paper honeycomb cores are given. Some of the factors which are considered in choosing sandwich facings and adhesives are given.

Key words: Adhesive; paper honeycomb; sandwich facings; sandwich panels.

1. Introduction

Light weight in buildings is not necessarily a panacea to the building industry. It can be advantageous when the saving in weight results in some functional or economic gain. When a reduction in weight is required it can be achieved by either one or both of two methods: first, by the use of material in a more efficient manner; and second, by the use of materials with high strength-to-density ratios. Structural sandwiches for buildings can be an example of both of these methods, but usually only the first is used because of the higher cost of high strength materials.

Structural sandwiches are a logical choice when designing lightweight buildings and they are being use quite extensively in the U.S. at the present time. Several of the sandwiches being used were developed by the aerospace industry. This industry requires very high strength-to-weight ratios in their structural components. Structural sandwiches with honeycomb cores and high strength facings (see fig. 1) provide the highest flexural rigidities with very low weights.

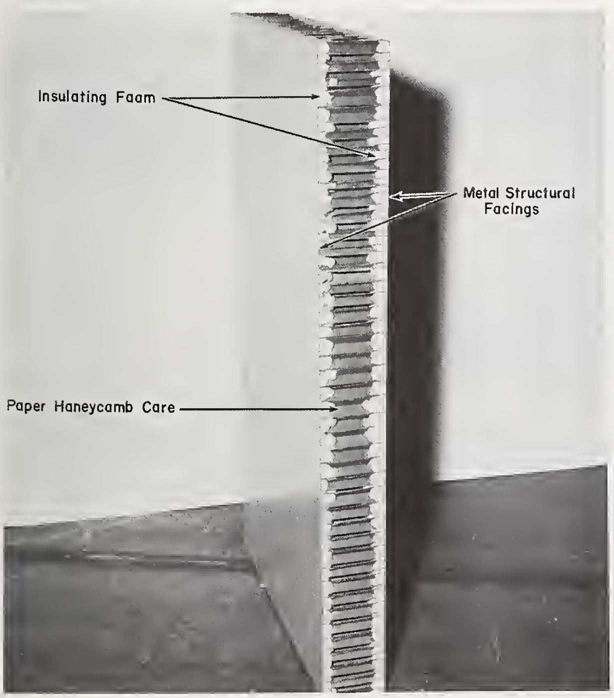

FIGURE 1. *Typical paper honeycomb sandwich panel.*

The honeycomb cores for aircraft and space vehicle components are being made from a variety of materials, such as paper, plastic, or even titanium. The facings used on these sandwiches vary from materials such as aluminum to graphite or boron fiber reinforced plastics.

Table 1 is a listing of some of the sandwiches, which are being used or are being proposed for use in buildings at the present time. It should be noted that most of these include paper honeycomb as a core material.

The plastic foam listed here is not used widely in structural sandwiches because of the low shear strength of most of these foams. When used as a core, the plastic foam is relied on only to provide lateral stiffening for the facing and auxiliary structural members are attached to the facings.

Figures 2 and 3 illustrate two structures which are being produced in the U.S. and which utilize sandwich panel material. The building shown in figure 2 was constructed in our laboratory using aluminum-faced, paper honeycomb panels 76mm (3 inches) thick. These panels, which were used in walls, roof, and floors, were connected together by means of sheet metal screws and aluminum extrusions.

The building shown in figure 3 is constructed of sandwich panels using paper honeycomb cores and steel facings. This building is a single-story, single-family house prefabricated by one of the large corporations in the U.S. The complete building is designed to be set up in a matter of hours on concrete piers.

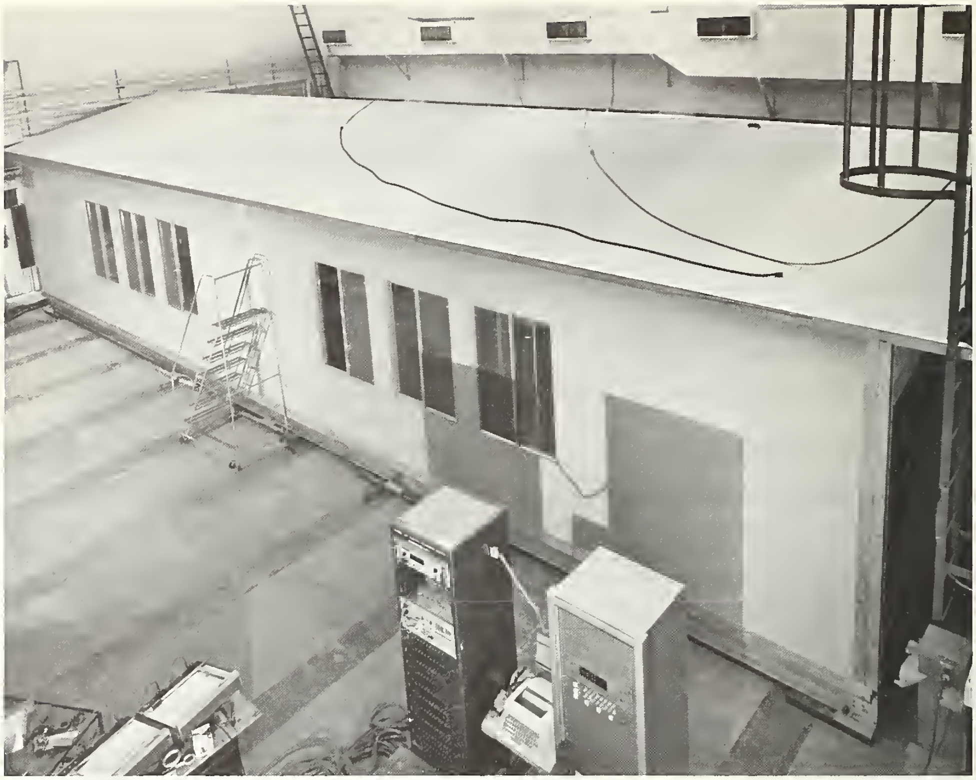

FIGURE 2. *Commercially available building constructed with aluminum-faced sandwich panels.*

FIGURE 3. *Single family house constructed with steel-faced sandwich panels.*

TABLE 1. *Typical structural sandwich panels for buildings*

Type	Core			Structural facing			Additional		
	Thickness		Material	Thickness		Material	Facing	Weight[1]	
	mm	*(in)*		*mm*	*(in)*			*kg/m²*	*(lb/ft ²)*
1	76.	(3)	Paper honeycomb	0.6	(0.024)	Aluminum	none	5.9	(1.2)
2	76.	(3)	Paper honeycomb and plastic foam	0.5	(.020)	Steel	none	10.7	(2.2)
3	51.	(2)	Aluminum honeycomb	1.6	(.064)	High pressure laminate	none	—	—
4	76.	(3)	Paper honeycomb	3.6	(.140)	FRP [2]	Gypsum board	32.2	(6.6)
5	102.	(4)	Paper honeycomb	3.2	(.125)	Cement asbestos board	none	18.6	(3.8)
6	56.	(2.25)	Plastic foam[3]	3.2	(.125)	Cement asbestos board	Gypsum board	—	—
7	89.	(3.5)	Corrugated FRP	2.5	(.100)	FRP	none	14.6	(3.0)

[1] Weight per unit area of panel.
[2] FRP indicates fiberglass reinforced plastic.
[3] This panel has a structural aluminum frame.

2. Honeycomb Cores

Honeycombs suitable for use as cores in sandwich panels are being produced from many different materials but essentially from those materials which can be formed into thin sheets. Some of the materials now being used for honeycomb are: kraft paper, nylon paper, polyethylene, fiberglass (and other fibers) reinforced plastics, aluminum, stainless steel, and titanium.

With each material, the most frequently used honeycomb has a hexagonal configuration (see fig. 4), but other configurations are being made. Some of these other configurations are designed for applications where special qualities such as double curvature are required.

The structural sandwich panels for buildings are almost always made with kraft paper honeycombs. Kraft paper is available in many different weights and thicknesses and is low in cost in comparison with other materials used for honeycomb.

The kraft paper is usually modified by impregnation with a phenolic resin. The phenolic resin improves both the dry and wet strength, and imparts fungus resistance to the paper. Other treatments and resins are sometimes used to impart special properties to the honeycomb.

The mechanical properties and cost of kraft paper honeycomb vary with the weight of the paper, amount and type of resin impregnation, and cell size. The relative costs of some typical honeycombs are given in table 2. In general, the mechanical properties can be estimated from the unit weight of the expanded honeycomb.

The curves of figures 5 and 6 indicate the effect of the unit weight of some typical honeycombs on their shear and flatwise compressive strength. It should be noted that the strength values indicated in figures 5 and 6 are for "dry" specimens 25.4mm (1 inch) thick and that the strengths will be different for "wet" paper

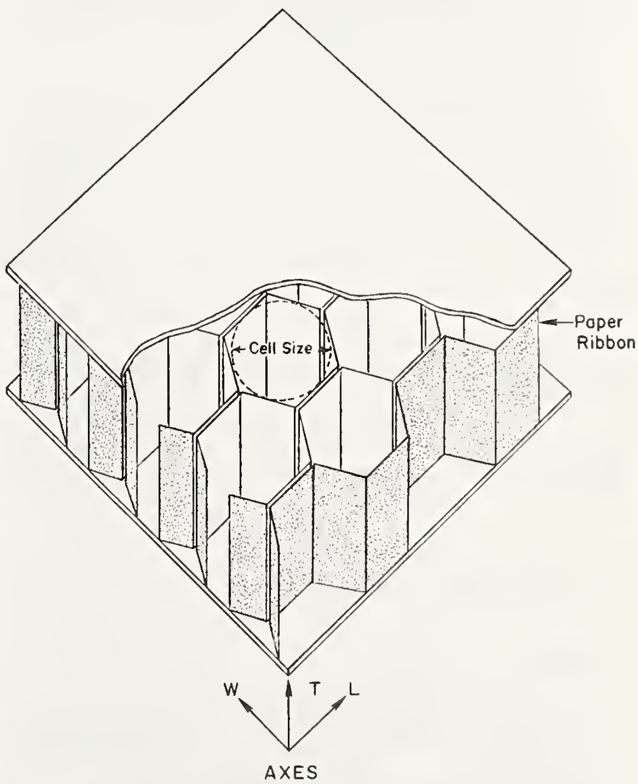

FIGURE 4. *Standard terms used with hexagonal honeycombs.*

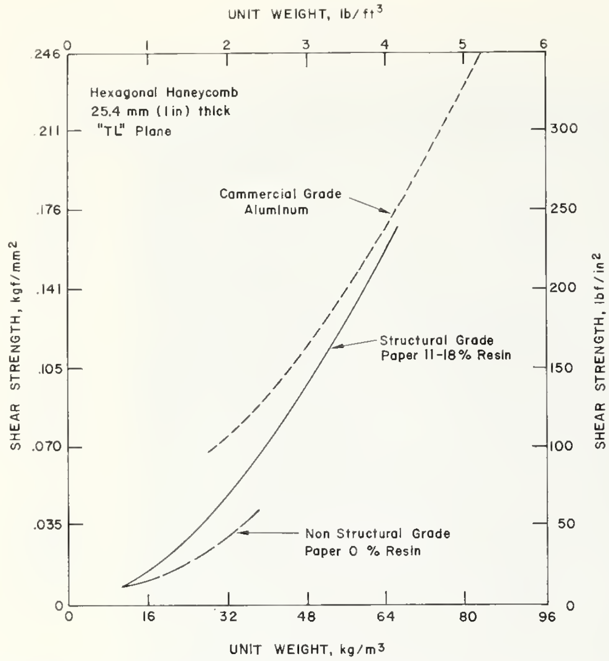

FIGURE 5. *Typical shear strength values for hexagonal honeycomb in the "TL" plane.*

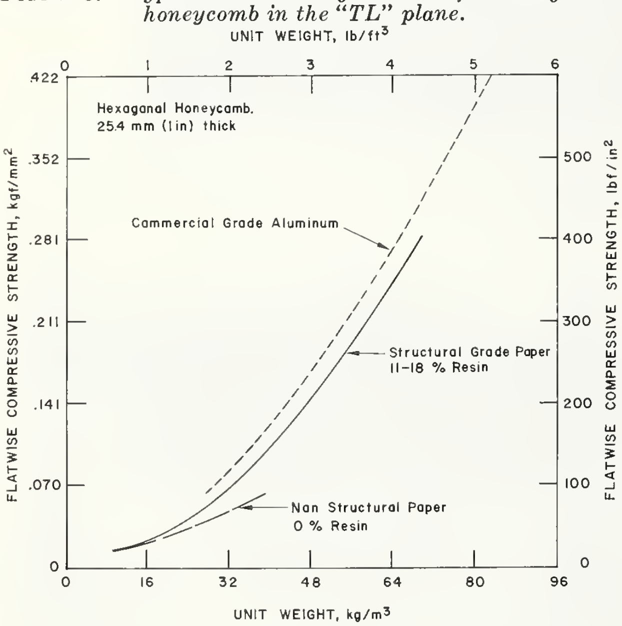

FIGURE 6. *Typical compressive strength values for hexagonal honeycomb.*

honeycomb specimens and for other thicknesses.

The term "dry" denotes paper honeycomb at equilibrium with room temperature air at 50 percent relative humidity. The moisture content of the paper at these conditions is about 5 percent by weight. All the mechanical properties of paper are affected by moisture content. The amount of moisture in a paper at a particular humidity condition is affected significantly by the amount and type of resin impregnation. Thus, it is necessary to determine the exact effect of various humidity conditions on the mechanical properties of a given paper. It is reasonable to expect that a paper will have only 50 to 60 percent of its "dry" strength when at equilibrium with 100 percent relative humidity, and even less after immersion in water.

TABLE 2. *Comparison of honeycomb costs**

Honeycomb type	Relative cost
Nonstructural grade, paper (0% resin impregnation)	1.0
Structural grade, paper (11-18% resin impregnation)	1.2
Fire-resistant, structural, paper	1.4
High strength, water resistant, paper (25-35% resin impregnation)	2.6
Commercial grade, aluminum	3.1

* Based on 25.4mm (1 inch) thick honeycomb weighing approximately 32. kg/m^3 (2 lb/ft^3).

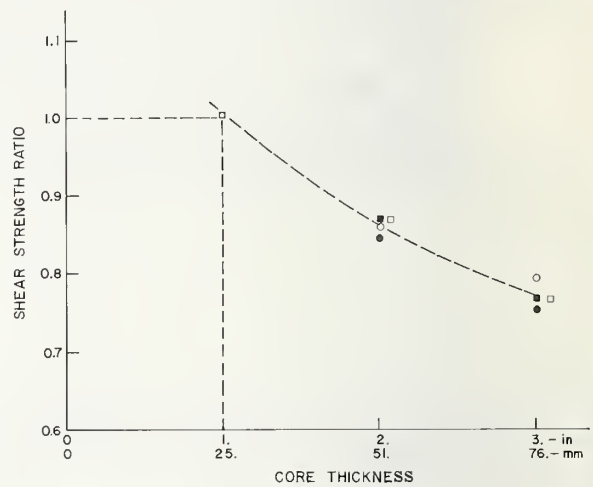

FIGURE 7. *Effect of thickness on shear strength of honeycomb.*

Figure 7 indicates clearly the effect that the thickness of the honeycomb core has on the shear strength. The effect of the thickness on the compressive strength is not very significant for thicknesses greater than 25.4mm (1 inch).

The method of manufacturing honeycombs results in shear strengths that vary with direction. Figure 4 illustrates the commonly accepted method of indicating the orientation of honeycombs. The "L" direction is parallel to the paper ribbon and the "W" direction is perpendicular. For a typical hexagonal honeycomb the shear strength and modulus of rigidity in the "TW" plane is about 40 percent less than that in the "TL" plane. This directional variation in properties is unfortunate because the strong "L" direction is with the width of the honeycomb as produced (not over 1.22m at present). If the sandwich designer wants to take advantage of the strong direction in a flexural member he must splice a number of pieces of core together in such a manner that the shear stresses can be transferred from piece to piece.

The thermal insulation provided by paper honeycomb as the core in a sandwich panel is insufficient for many applications. When added insulation is required, some form of insulating material is placed in the honeycomb cells. Generally some type of plastic foam is used, but other materials such as vermiculite, perlite, fiberglass, or mineral wool are also used in the cells.

3. Facings

The structural facings for sandwich panels can be made of almost any material with reliable mechanical properties. The higher strength materials such as the metals or fiber reinforced composite are generally used as the structural facings, but service factors such as fire, impact, abrasion, and concentrated loads, greatly influence the selection.

Closely allied with these selection factors is the cost of lamination because the choice of the adhesive and the subsequent bonding process are interrelated with the choice of the facing material. Damage to the facings in handling and shipping is many times an unexpected cost item.

Aluminum and steel are widely used as facings, because they can be purchased with the surface already prepared for adhesive bonding. This prepared surface greatly simplifies the sandwich bonding process for the panel producer. In addition, both aluminum and steel are available in coil form with a variety of mill-applied, finished surfaces which have proven to be very durable.

Fiberglass reinforced plastic (FRP) are being used for facing on sandwiches which are laminated by using the matrix-plastic as the bonding adhesive.

In some applications additional sheet material is bonded to the exposed surface of the primary structural facing. This is done when some characteristics of the panel must be modified. For example, the Type 4 sandwich panel of table 1 has primary structural facings of FRP, but gypsum board was bonded to each face in order to provide better fire resistance and lower sound transmission.

Sandwich panels will always have a tendency to bow or bend out of plane because of differences in the temperature and/or in the moisture content of the two facings. This tendency can be reduced by proper choice of the facing materials and thickness. The usual practice is to have a symmetrical (balanced) sandwich, i.e., identical facings on both sides of the sandwich.

Bowing of the sandwich panel is usually partially restrained by other components in the building. When this restraint and tendency to bow are both significant, unusual stress conditions within the sandwich may induce delamination of the panel.

4. Adhesive Bonding

The subject of the adhesive bonding of sandwich panels is so evolutionary and intricate that it can not be adequately covered in this paper. However, a brief mention of some basic precautions is in order. Further information can be gained by consulting the references cited below[1,2] and reputable adhesive manufacturers' literature.

Stated simply, a sandwich panel has a relatively thick, low strength core bonded to relatively thin, high strength facings where the important word in this description is "bonded." A failure of the bond results in a loss in structural integrity of the sandwich panel.

Under ideal conditions many adhesives will supply the required bond, but ideal conditions seldom occur in a building. For example, significant amounts of moisture, usually as vapor, will penetrate, sandwich panels under service conditions even when they have metal facings. High humidity within the panel can degrade the bond, but when the high humidity is combined with the high temperature induced by solar heating the degradation can be severe.

Moisture combined with elevated temperatures can degrade the bond by several methods; one, by degradation of the adhesive itself, two, by corrosion of the facing material and three, by chemical reaction with one or more of the other materials within the panel.

Some adhesives are water soluble while others allow the moisture to penetrate through and deposit on the substrate and thus weakening the bond.

Adhesives can be classified in a number of ways, but for sandwich panels they should be classified according to the bond strength and durability attained when used with the particular facings and core chosen. In general, wood and wood products (kraft paper for instance) are easily bonded, whereas, metals require greater care and cleanliness.

5. Summary

The construction industry in the U.S. is now using several different sandwich panel systems and is contemplating the use of others. Many

[1] Symposium on Structural Adhesives Bonding, Editor, Michael J. Bodnar (Interscience Publishers, New York City, New York, 1966).
[2] U. S. Department of Defense, Military Handbook, Structural Sandwich Composites, MIL-HDBK-23A, 1968.

of these systems utilize paper honeycomb as the core material in the sandwiches.

Paper honeycomb is available in a variety of weights, thicknesses and impregnations which control the mechanical properties of the core. Insulating material is often placed in the honeycomb cells to improve the thermal characteristics.

The facing materials most widely used for structural sandwiches are prefinished aluminum or steel and fiberglass reinforced plastic. Additional facings, such as gypsum board, are sometimes added to improve the performance of the sandwich.

The most important single element in a structural sandwich is the bond between the facings and core. The choice of the adhesive and the bonding process should be based on the assumption that the system will be exposed to adverse conditions in service.

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This paper presents a resume of current practice in the U.S. with regard to the use of sandwich panels in single-story buildings. A description and the properties of typical paper honeycomb cores are given. Some of the factors which are considered in choosing sandwich facings and adhesives are given.

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