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by

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Structural Sandwich Panels In Housing

by R. E. Platts

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PREFABRICATION HAS DEVELOPED more rapidly in providing housing for the Canadian North than for the rest of Canada, because of the brief northern construction season and high costs of transportation, labour, and overhead. During the past decade military, governmental, and commercial projects in the North have come to rely on framed stressed skin prefabricated units for almost all housing. Recently structural sandwich types of stressed skin systems have been used in northern housing, and these also show some promise for housing in general, offering maximum strength-to-weight ratios with given materials.

Following the success of sandwich construction in aircraft, beginning with the famous British Mosquito bomber, many American and some Canadian companies have developed and tested sandwich house systems during the last twelve years. Problems of bonding and costs have been common, but some well proven sandwich constructions are reported to have given lower costs than site-built wood-frame housing. The marketing of sandwich constructions is reported to have been restricted by the interpretation of municipal building codes by local inspectors who lack information about sandwich engineering and history. The N.R.C. Division of Building Research is engaged in studies of northern housing and of house prefabrication in general. This work includes an evaluation of the potentialities of sandwich construction and an appraisal of its performance characteristics. It is hoped that the information so far obtained and now reported will assist others in their assessments of sandwich constructions.

THE STRUCTURAL SANDWICH

Structural sandwich construction can provide the maximum strength and rigidity possible in panel form with given materials. The system uses any relatively strong sheet material for "skins", fully bonded to a light "core" which is sandwiched between them. True "stressed skin" action is achieved, with the skins taking the direct stresses as the panel is compressed or flexed, and the core taking the shear and preventing buckling of the skins. Since the load-bearing skins are at the extreme distance from the neutral axis, the sandwich provides the greatest section modulus obtainable from the given skin material, and thus the highest efficiency in either column or beam action.

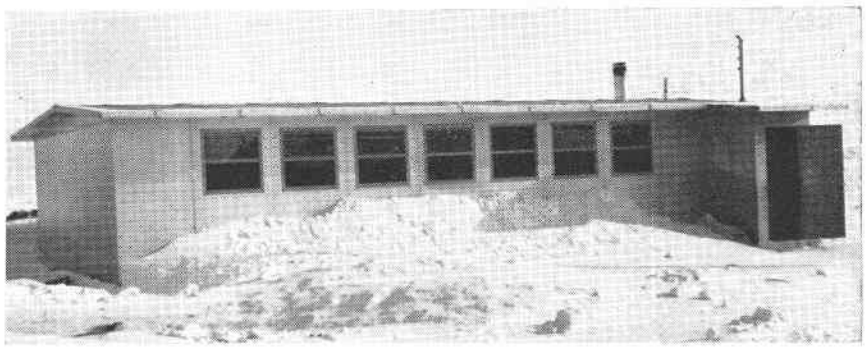
The efficiency of the sandwich action can be shown by considering as an example a sandwich panel 2-in. thick, with ⅛-in. tempered hardboard skins. Weighing only 1.7 lb/sq ft, this panel can be used as a load-bearing wall comparing with conventional stud frame walls weighing over 8 lb/sq ft. Further, such a sandwich can incorporate the necessary wall structure, the interior and exterior finish, vapour barrier and thermal insulation in one unit using just three materials. The conventional frame wall may use an assembly of nine separate materials for the same functions. In bending, a 4-in. thick sandwich with ¼-in. plywood skins can span 12 ft and carry 50 psf with a deflection of less than 1/300 of the span. Much less wasteful use of resources is clearly possible with sandwich construction. Materials, production techniques, and applications are already well developed.

MATERIALS

Skins

The structural performance of the sandwich depends on the three components – skins, cores, and adhesives; failure in any one means failure of the whole. The choice of materials is of vital importance. Skins for structural sandwich manufacture can be one of several proven sheet materials that have been developed in the past three decades. Exterior grade plywoods have remained to the fore in stressed skin and sandwich applications. Usual thickness is ¼-in. but kraft overlaid plywoods and single veneers ⅛-in. thick have been successfully used. Dimensional stability is good. Surface grain checking presents maintenance problems, but scored or overlaid surfaces go far to correct this difficulty. Oil-treated hardboards ⅛ to ¼-in. thick are often used as sandwich skins, giving fair dimensional stability, strength, and a good painting or coating surface. Their low elastic modulus makes them more applicable as wall panels than as panels in bending.

Sheet aluminum is being increasingly used in sandwiches, in thicknesses of 1/50-in. and more. Hardboard backings between aluminum skins and the core are usually necessary to improve dent resistance. Acrylic lacquers, chemical treatments, colour anodizing and baked vinyl coatings are used for



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Northern Sandwich Panel School

colouring the skins. Stainless steels, porcelainized steels, and asbestos boards form sandwich skins for curtain wall construction.

Paper plastics–high pressure laminates of phenolic impregnated krafts – are proving promising as sandwich skins. Some developers in the southern United States are reported to offer these materials at prices lower than hardboards. Their modulus and dimensional stability are reported to compare with tempered hardboards; strengths are higher. Fibre-reinforced plastics are used in some sandwich panels. They can provide compound curved surfaces and meet wide design variations, but costs are usually too high for housing panels. Reinforcing fibres are glass, synthetic fibres, asbestos, jute, sisal; these are bonded and coated with polyester or epoxy resins. Working stresses can be 20,000 to 30,000 psi, at only one quarter the weight of steel.

Adhesives

Adhesives have held the key to most sandwich panel advances. In general, animal and vegetable glues are too prone to moisture attack to be suitable for structural sandwich use. The development of plastic resin adhesives has, however, allowed the development of structural sandwiches as dependable building systems. The phenol formaldehydes are the oldest and remain one of the most common waterproof structural adhesives for woods. They need high temperatures and pressures for thermosetting, however, and this rules out their use with many sandwich core materials. Resorcinal formaldehyde is equally waterproof, can cure at room temperatures, but is usually higher in cost. It is often used to modify phenolics for wood-skinned sandwiches. Urea formaldehydes are inexpensive but not totally waterproof; they are sometimes used in well protected panels. Like all thermosetting plastics, these adhesives are relatively free from creep tendencies.

Metal skins can be strongly bonded with the new epoxy resins. Flexibility of the bond is poor, and nitrile rubbers or vinyls are used as elastomers to modify the epoxies and phenolics in order to give a strong and more resilient bond. Shear strengths up to 5,000 psi can be obtained. Curing time is slow; at least one half to one hour is needed, so production speed is limited.

Increasingly used as structural sandwich adhesives are the neoprene-phenolic rubber-resins, which are water resistant, resilient, and combine the lowest structural adhesive cost with ease of high speed panel fabrication. They will bond metals, hardboards, and other skins to most core materials, and can be free from shear creep at most sandwich stress levels. Their initial pressure-sensitive tack, followed by age thermosetting, allows very fast pinch-roll panel production.

Cores

Core materials should be lightweight and yet have the strength and modulus necessary to stabilize the faces and to carry the distributed shear loads. Paper honeycomb cores have been thoroughly investigated and developed, and offer a wide range of design features as well as good dependability. These cores are usually made up of kraft paper strips bonded together to form polygonal cells normal to the plane of the sandwich, closely resembling a true honeycomb. The paper is nearly always impregnated with phenolic or sometimes polyester plastic resins, giving it good wet strength and resistance to rot or fungus. Strength/weight ratio is very high; creep tendencies are small; cost is reasonable. Because the thermal insulation provided by honeycomb oriented normal to the panel plane is only fair (k value over 0.45)*, expanded plastics, silica, or micas are sometimes used to fill the honeycomb cells to provide better insulation. Disadvantages of the honeycomb are adhesion difficulties and their lack of support against local denting or puncturing of skins. Since only thin paper edges are usually in contact with the skins, the area of bond of core-to-skin is small. Adhesives must be chosen that will wet out and "fillet" at the junction of paper and skin in order to effectively increase the bond area.

**The "k value" is the coefficient of thermal conductivity expressed in Btu/sq ft/hr/in. of thickness. The usual range of k for insulating materials is 0.25 to 0.35, with the lower numbers indicating better insulating ability.*

If mechanical properties only are to be considered, balsa wood is one of the best low density sandwich cores. Its high variability in properties and defects, however, calls for careful inspection and more than half is usually rejected before fabrication. Foamed plastics offer versatility and low cost but have some disadvantages. Foamed polystyrenes are the least expensive and most commonly used. The extruded foam polystyrenes have generally given way to the bead foam types; these are available in larger boards or can be foamed in the mold. The biggest advantages of the foamed polystyrenes are their high strength/weight ratio, resiliency, excellent thermal insulation, and high resistance to water vapour transmission and water absorption. Their disadvantages are due to their being thermoplastics: their strength properties decrease with higher temperatures, becoming very poor above 180°F., and they are subject to creep. The creep problem does not usually affect panels in column loading, and shear creep in panels in bending has been effectively limited by light wood edge frames used as shear webs. Potentially, the foamed polystyrenes allow economic sandwich fabrication even at fairly low production volume, requiring inexpensive low-pressure low-temperature bending, and offering foaming-in-mold to any shape. K values are about 0.24.

Polyurethane foams are promising materials for sandwich cores. They offer foaming-in-mold between skins, and often need no adhesives, themselves bonding to many skin materials. They allow higher strength and elasticity modulus than the polystyrenes, but cost almost twice as much. Closed cell polyurethanes, which give lower water absorption and water vapour transmission, have been developed only recently. Since the polyurethanes are thermosetting foams, they are stable at high temperatures and can be free from creep. Recent developments with inert gas-blown polyurethanes have achieved k values as low as 0.12. Usual polyurethanes give k values of about 0.24.

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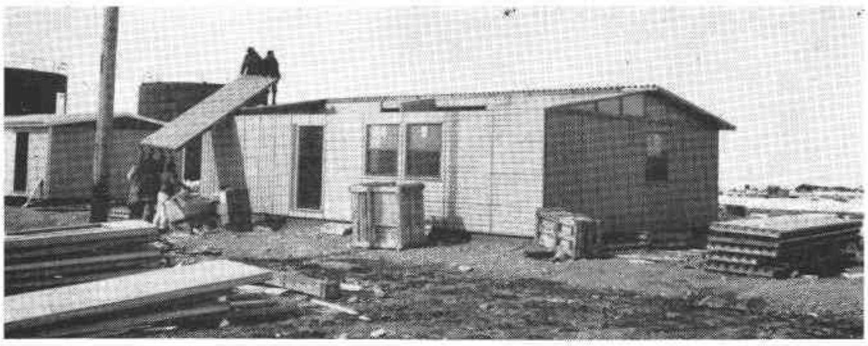

Closing in Stressed Skin Northern House

Other sandwich core materials have special uses which are limited by their high cost and fabrication difficulties. Foam glass, foam phenolics, and calcium silicates are used in sandwich panels that require higher fire ratings, but these foams are too brittle to allow some skins to be stressed under load without core fracture. The use of resilient adhesives to overcome this disadvantage usually offsets the fire-resistant advantages of the core itself.

SANDWICH PANEL DESIGN

These are the materials usually used in structural sandwiches for housing. Structural sandwich panels may be designed with them for almost any given application, by choosing the materials according to their separate and combined properties. Skins are chosen to take the required loads within given deflection limits, and to withstand environmental conditions. Cores must provide the strength and elasticity to stabilize the skins and to carry shear stresses, as well as to furnish thermal insulation and vapour resistance as needed. Adhesives must bond the whole panel and maintain the bond under all expected conditions for a dependable service life.

Sandwich design parallels beam or column design to some extent, with the skins representing the flanges and the core representing the web of an "I" beam or "H" column. Considerations of the elastic stability of skin and core and the effects of shear distortion of the core become rigorous in exact sandwich design, and simple approximate methods are usually used, followed by tests on mock-up panels. Many types of structural sandwich panels have been subjected to a considerable program of severe laboratory testing. Some very light sandwich constructions have now given over twelve years of service as complete house shells, with no defects reported.

FACTORS IN SANDWICH SUITABILITY

Four service factors become more important in sandwich design than in conventional practice and only full consideration of these factors will permit dependable sandwich panel house design. These factors are – condensation within the panel, differential movement of the skins, sound transmission, and fire resistance.

The sandwich inherently forms a vapour trap between inner and outer skins, since the skins themselves, the finish coating, or the adhesive layers usually form vapour barriers of about equal permeance on both panel surfaces. Accordingly, condensation control in sandwich construction usually involves minimizing rather than preventing condensation within the panel, so that the amount of winter condensate is kept within limits and can be removed in summer drying. Low permeance skins and cores are desirable, and the joint details should be carefully designed to provide good sealing on the inside and adequate "breathing" to the outside.

Differential dimensional change of sandwich skins can produce bowing in the same manner as bimetallic strip curling. Because the skins are an appreciable distance apart and continuously supported, the bowing is not usually critical except in the initial erection of the panels. The panel will bow in a smooth undistorted compound curve; the core will prevent skin "oil-canning" or other unsightly wrinkling. As an example, an aluminum skinned sandwich 4 ft square and 3-in. thick, will bow smoothly about ¼-in. when the skin temperatures are 100°F apart. At this extreme condition, the deflection/span ratio is only about 1/200 and is in no way unsightly.

With skins of most fibrous materials, bowing can result from unequal skin movement caused by unequal skin moisture contents. Surface coatings on fibreboards or "hardboard" do not affect their final equilibrium moisture contents at given humidities, but coatings greatly change their rate of moisture absorption, to the point where weeks of wetting may be required to cause troublesome moisture contents. Impregnants – oils or resins that "wet out" the fibrous boards – can reduce the moisture-absorbing capacity of fibreboards to some extent, allowing decreased equilibrium moisture contents and greatly decreasing the rate of dimensional change.

High sound transmission can be a problem in a sandwich house: the lightweight panels are not as effective as heavier panels in reducing sound transmission. Resilient floorings or carpets and sound absorptive surfaces can be used to reduce the over-all noise level. Tight door seals, storage areas arranged between living and sleeping areas, and other means can reduce the sound transmission.

Fire safety will be less than that of plastered conventional construction. Although flame spread will depend on the choice of skin and finish (as in any panel) the question of fire resistance is very important in sandwich design, especially if heat softening cores such as thermoplastics are used without reinforcement. Other core materials give fair heat resistance. The thermoplastics themselves can be satisfactory for housing use, if panel edge frames are used to maintain adequate stressed skin strengths in the wall, floor, or roof panels for reasonable times when exposed to fires. This solution is practicable and inexpensive.

JOINT DESIGN

The success of any panel assembly depends directly on the joint design. Panel joints must satisfy many requirements, including the most difficult one of simplicity. The joint should provide for alignment of bowed panels during assembly and maintain the alignment during subsequent movement. Thermal bridging should be avoided. Joint sealing should restrict vapour penetration from the inside and wind and rain penetration from the outside. Racking re-

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Wall Assembly of Sandwich Northern Unit sistance must be adequate, assembly should be simple and rapid, and sometimes subsequent disassembly must be practicable.

To provide positive panel alignment, joint details are usually variations of tongue and groove, spline, offset lap, or batten types. Joints often incorporate compressible gaskets of synthetic elastomers in order to allow wide assembly and service tolerances and to provide good sealing. Mechanical fasteners are designed to compress these gaskets during the assembly of the panels. The fasteners can be nails or screws, but are usually bolts, inset cam hooks, or wedge-locked pins.

Where desirable, true continuous joints can be provided only by adhesives. Structural adhesives used for this purpose are the synthetic resins discussed previously. They must, of course, be catalyzed to cure at 70°F or less, and must usually be good gap fillers to perform satisfactorily under rough field application conditions. Portable radio frequency units are now used to "field cure" some adhesives. Final joint treatment entails protecting the raw skin edges and sometimes the application of coverings to accent the joints. Battens have traditionally been used but pressure-sensitive plastic or aluminum tapes are now being used with reported success.

SOME STRUCTURAL SANDWICH COSTS

The final and dominant criterion in evaluating new house shell systems is that of cost. Can their present or potential costs compete with conventional structures, which use the cheapest available materials, to provide reasonably low first costs? Reported costs of several proven sandwich panels are lower than the cost of corresponding conventional wood-frame house shells; potential costs should be considerably lower.

Perhaps the best known sandwich is the now common flush door, with wood veneer skins on paper honeycomb or wood grid cores; these retail at from 40 to 50¢ per square foot. Adding an insulating core and allowing for finishing costs indicates a sandwich wall panel cost of under 65¢ per square foot. Some builders in the southern United States use 8-ft high flush doors to form a complete house shell, and they report considerable savings. More significantly, in a recent sandwich house development, a large American prefabricator has estimated a cost in place of 80¢ per square foot for his panels. A Canadian prefabricator estimates his prototype sandwich panels in place at two-thirds the cost of conventional frame walls. Recent development in cores and adhesives should result in still lower panel costs.

POTENTIAL DEVELOPMENTS

Sandwich construction offers the advantages of reduced shop labour, reduced and simplified materials handling, and potentially lower costs to the house manufacturer, with the disadvantages of much more critical shop control and testing requirements. These advantages and those of reduced weight and transportation costs (a sandwich house can weigh less than one-third as much as a conventional wood-frame house) will mean that advances in sandwich housing will come mainly through the house manufacturer or prefabricator. Progress in house construction advances slowly, partly due to the complexity of the industry, its financing and marketing, and partly due to the restrictive effect of the many varied municipal building by-laws. Activity in sandwich production, testing and application is increasing, however, and as information on durability and suitability becomes better known, sandwich housing may well earn a larger share of the Canadian market.

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