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WAFFLE - TYPE CORE MATERIAL FOR SANDWICH CONSTRUCTION

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WAFFLE-TYPE CORE MATERIAL FOR SANDWICH CONSTRUCTIONS

Prepared by:

H. A. Perry, Jr.

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ABSTRACT: A fabricated core material is described which consists of a single sheet with symmetrical truncated pyramidal indentations, alike on both sides, resembling the geometry of a waffle. A waffle core of rigid sheet material when bonded between two flat, high strength faces, produces a strong, light-weight structure. Two separate channels exist for the flow of heat-transfer media in the plane of the sheet.

A number of sandwich panels of this construction have been fabricated and tested, exhibiting high strength-weight ratios and excellent stiffness. The panels compared well in these properties with a typical panel of honeycomb core sandwich construction.

The "Waffle" type of sandwich construction appears potentially to be of considerable value in the fabrication of aircraft parts, radomes, solid blast protective flooring and heat exchangers. It offers a solution to aircraft de-icing and flight cooling problems.

Chemistry Research Department
U. S. NAVAL ORINANCE LABORATORY
White Oak, Maryland

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7 July 1958

This work was carried out under NOL Task SS-19 during 1947 and 1948. It should be understood that the materials properties reported do not reflect the properties which could be obtained currently through the use of improved reinforcements, resins and adhesives which are now available. This development was terminated in 1948 for lack of urgent applications at that time for this class of material. It is reported now because of the potentialities of the material as a possible means for solving current problems of great urgency in connection with the surface cooling of supersonic aircraft and missiles. Accordingly, this report is issued under the authority of NOL 126.

W. W. WILBOURNE
Captain, USN
Commander

Alfred Lightbody
A. LIGHTBODY
By direction

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WAFFLE-TYPE CORE MATERIAL FOR SANDWICH CONSTRUCTIONS

INTRODUCTION

1. As a result of a need for improvements and a reduction of cost of structural sandwich materials, particularly for radome construction, the writer has developed a new type of sandwich construction which shows considerable promise of high strength weight ratios, is susceptible to mass production, probably possesses good microwave characteristics and offers new and useful properties of potential interest in the field of surface heating or cooling applications. The ideas which led to this development were brought by the writer to NOL from Radiation Laboratory, MIT, in 1945.

2. Sandwich construction consists of a multi-layer sheet having thin, high strength faces with a thick, low density core material sandwiched in between. The function of the thin faces is to carry the major part of the applied loads. The function of the core is to keep the faces from deflecting independently, to stabilize the faces against buckling and to impart stiffness to the assembly. A good sandwich design is one in which the strengths of the core, and of the bond between it and the faces, in shear and tension are such that the full strength of the faces and the core are developed during load to failure without excess strength or weight in the faces or core. An optimum strength weight ratio is imperative in some applications, particularly for aircraft parts. In general, sandwich structures offer this advantage over, or are competitive with the best of, other types of construction.

3. Various core materials have been employed in sandwich construction in the past, commonly falling into two categories: strong natural or synthetic cellular materials such as foamed hard rubber or balsa; corrugated or grid type fabrications such as the "honeycomb" type material or corrugated sheeting used in box construction. The core material described here falls in the latter category and offers certain pronounced advantages over existing materials.

Core Design

4. The "waffle" core material is produced by deforming a plastic sheet with symmetrical truncated pyramidal indentations, alike on both sides, until the sheet resembles a waffle. As a core in a sandwich structure the sheet behaves as do the cross braces in a girder. Flat areas are available on the surface of the core material, permitting adequate bonding of the core to the faces. The strength properties of the resultant sandwich are alike in at least two directions in the plane of the sandwich, with properties differing not greatly from these in other directions in the sheet. This

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feature contrasts markedly with the traditional corrugated box construction wherein the strength properties vary greatly with direction.

5. The feature of nearly uniform strength in various directions in the "waffle" sandwich is demonstrated also by the "honeycomb" sandwich, but the former is very likely to be easier and cheaper to produce than the latter. This may be seen by comparing the methods of fabrication. Honeycomb core material is produced by stacking corrugated sheets and gluing them into blocks from which slabs of desired thickness are cut with the walls of the honeycomb cells perpendicular to the plane of the sheet. This operation is of necessity a batch process. Waffle core material, on the other hand, is produced in one operation between two dies from sheet stock. Figure 1 shows the waffle type sandwich. Figure 2 shows an experimental die for producing the waffle core material. Figure 3 shows a cutaway view of a waffle type sandwich panel. Figure 4 gives the dimensions of core.

6. The particular design of waffle core produced and tested in this experiment was chosen arbitrarily. No attempt was made to make a preliminary evaluation of the stress distribution in the core and faces of such a sandwich. Rather, it was estimated on the basis of previous experience with honeycomb and foamed plastic core sandwiches that the spacing and face thicknesses chosen should provide good mechanical strength and also good radar transmission in the 3 centimeter wave length band. For example, the slope of the core webs is set at 63° , which is near Brewster's Angle for the minimum reflection of an electromagnetic wave from a dielectric sheet with parallel polarisation.

7. It is customary to consider that a sandwich face under stress behaves like a plate on a continuous elastic foundation. The theories of stress analysis in sandwiches are usually based on this premise. It is not likely that this is applicable in the case of the waffle sandwich. It is possible, however, that an analysis of the support given the faces by a waffle core may be based upon a theory of a column discontinuously supported. (Reference (1)). A theoretical analysis and an experimental evaluation of the following factors should result in higher strength-weight ratios.

Experimental Procedure

8. A die was fabricated by pegging machined steel truncated pyramids into steel plates. The pyramids were designed so that the space between the teeth of the dies when meshed was constant throughout at $0.030''$. Guide pins were provided to insure very accurate alignment of the two parts while closing.

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9. Waffle cores were produced as 4" x 9" panels in the steel die from knit cotton cloth and also from glass fiber mat. The sheet stock was impregnated with a polyester laminating resin, placed in the mold and cured under heat and pressure. Sandwich faces were molded between flat platens. The materials used and the conditions of cure were as follows:

Faces: (a) X-30,000 Mat - 35%; Plaskon 920-11 - 65%
(b) ECC-122 Glass cloth - 60%; Plaskon 920-11 - 40%.

Cure: 20'/280°F - at p.s.i.

Cores: (a) C126 Knit Cotton - 35%; Plaskon 920-11 - 60%
Selectron 5003 - 5%
(b) X-30,000 Mat - 35%; Plaskon 920-11
(c) C126 Knit Cotton - 35%; Plaskon 920-11 - 65%

Cure: 20'/280°F at slight pressure on an 8" 50 ton press.

10. Sandwich panels, 4" x 9", were produced by assembling a core and two like face sheets using Plycosite adhesive and bonded at 300°F for 45 minutes at 50 psi between flat platens. The following combinations were assembled:

- a. Glass mat cores with glass mat faces.
- b. Glass mat cores with glass cloth faces.
- c. Knit cotton cores with glass mat faces.
- d. Knit cotton cores with glass cloth faces.

11. The following tests were run on the experimental panels and compared with a typical honeycomb panel on hand at this laboratory:

- a. Edgewise Compressive Strength
- b. Flatwise Compressive Strength
- c. Flatwise Flexural Strength, Proportional and Ultimate
- d. Modulus of Elasticity of Flexure

The results of the tests and the characteristics of the panels may be found in Tables 1 through 4. The strength properties of the various panels are correlated with skin thickness in Figures 5 through 8. The composition and properties of the honeycomb panel tested are shown in Table 5. The strength weight ratios and the elastic properties in flexure of waffle core panel No. 9 are compared with those of the honeycomb core panel in Table 6. Panel No. 9 was chosen for this comparison as the best of the lot.

Discussion

12. In view of the limited data available, the curves shown in the enclosure should not be construed to represent other than general trends. For instance, the inflections of the plots of strength

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properties and stiffness versus skin thickness cannot be interpreted without assuming that panels No. 15 and perhaps No. 24 were defective. However, general trends may be observed in this data. As expected, the strength and stiffness of the panels increase with skin thickness within the range of this experiment. Also, a glass mat core in general provides greater mechanical strength to a sandwich than does a cotton core. Lastly, the glass mat faces appear generally to impart greater strength at fracture than do glass cloth faces, and glass cloth faces impart greater stiffness than do glass mat faces. However, the best individual panel of those produced in this experiment appears to be a sandwich consisting of a glass mat core with 0.030" glass cloth faces (panel No. 9). More data should be collected before final conclusions may be drawn.

13. It may be noted that the waffle sandwich Panel No. 9 and the honeycomb panel are in general comparable, and that the stiffness and strength weight ratio of proportional strength in flexure of the waffle sandwich are higher than in the honeycomb sandwich. A comparison of the data on flatwise compressive strength reveals that in some instances, particularly with cotton cores, the waffle sandwiches are twice as strong as the honeycomb sandwich.

14. It has been demonstrated in the laboratory that glass mat cores can be postformed into compound curvatures of relatively short radius without difficulty and without greatly altering the thickness of the sheet. This property will probably be common among a number of materials from which cores may be fabricated and will permit the construction of sandwich structures with compound curves. Tables 7 and 8 show some of the known uses of sandwich structures together with the important design parameters governing their use.

15. Of considerable current interest is the feature that channels exist in the plane of the sheet which will permit the flow of fluids through the sheet. This may permit the de-icing of surface cooling of radomes, missile noses and leading edges by means of heat transfer liquids or gases. It may also permit the use of such sandwiches as construction materials where radiant heating or cooling is desired as in interior finish, as in aircraft cabins. Further, it may permit the construction of fluid heat exchangers, since two fluids may be caused to flow separately within the one sandwich and a large area of thin core webs will separate the fluids. Some of the possibilities are shown in Figure 9.

16. Of further interest is the possibility of fabricating the waffle core material of a rubber stock of about 50 durometer. When assembled in sandwich form, either with hard or elastic faces, it may act as a solid blast protective flooring material for ship-board installations (reference (2)).

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Production Techniques

17. The type of die used in this experiment is applicable to larger dies. Products molded in such dies may be held to close tolerances. Steel dies would be quite suitable for drawing metal waffle cores. It is likely, however, that for plastic cores a low cost fabrication technique using softer metals may be employed for the construction of dies. Die cast pyramids pegged to plates are of interest. Solid castings of aluminum or zinc base alloys may be feasible.

18. In the production of waffle cores and sandwiches the dimensions of the dies will depend upon the required thickness of the core material. In constructing sandwiches it is often the case that inserts and fittings are incorporated for stress distribution at points of attachment and for various other purposes. Since it is desirable to limit the number of designs and sizes of inserts and fittings in sandwich construction, particularly for aircraft, and since their dimensions are determined by core thickness rather than total thickness of the panels, obvious production economies result from standardizing on a relatively few thickness of core. The honeycomb industry has standardized wherever possible on 0.25", 0.3125", 0.375", 0.5", 0.625", 0.75" and 1.00". It would be feasible to develop dies for the production of waffle cores in this or a similar range of thickness.

19. The reduction in thickness of waffle cores after molding may be accomplished by rolling or pressing between hot surfaces. This permits an adjustment of the core thickness to fill the gaps between the above standard thicknesses. Although this feature has not been investigated to any extent, it is anticipated that the employment of this artifice in adjusting thickness will not cause excessive weakening of the resultant sandwich structure, but will merely result in an increase in the area of the flats and not affect the slant web structure materially.

Conclusions

20. The results of tests on experimental panels show that waffle type sandwiches constructed of rigid reinforced plastics are competitive in stiffness and strength weight ratios with an equivalent fiberglass honeycomb type sandwich panel. A variety of materials combinations are of interest in various ways, some for unique properties and others for materials economy. The material may be postformed to produce compound curves. This type of construction appears potentially to be of value in the fabrication of aircraft parts, radomes, solid blast protective flooring and heat exchangers. It may offer a means for the de-icing of leading edges and radomes in winter, and for the cooling of surfaces in supersonic flight. Also, it may provide convenient means for the fabrication of metallic microwave lenses.

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21. It is anticipated that this material may be further improved through a study of the geometry of cores and the properties of materials, that the number of potentially valuable naval applications may increase through further study of the material, and that a study of techniques will lead to the production of sandwich structures at speeds not heretofore attained and at costs under those for other sandwich constructions of like quality.

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TABLE 1

WAFFLE CORE SANDWICH TEST DATA

Faces - Glass Fiber Mat, X-30,000

Core - Glass Fiber Mat, X-30,000

Adhesive - Plycozite

<u>Property</u>	<u>Panel Number</u>			
	<u>(4)</u>	<u>(5)</u>	<u>(6)</u>	<u>(7)</u>
Face Thickness	0.030	0.025	0.020	0.020
Panel Thickness	0.383 0.346	-	0.350	-
Apparent Density-lbs/cu.ft.	30.1	-	24.0	-
Compressive Strength - psi				
Flatwise	-	900 822	-	-
Edgewise	1460 1545 1500	-	1100 1440 1255 1165	-
Flatwise Flexural Strength - psi, Ultimate	5640 7630	-	4760 5550	-
Proportional	2570 4100	-	3210 2570	-
Modulus of Elasticity psi X10 ⁶	0.398 0.579	-	0.339 0.364	-

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TABLE 2

WAFFLE CORE SANDWICH TEST DATA

Faces - Fiberglas Cloth ECC-112

Core - Glass Fiber mat, X-30,000

Adhesive - Plyozite, except panel (1) which contained Bostik

	Panel Number			(8)
	(1)	(9)	(2)	
Face Thickness - Inches	0.030	0.030	0.020	0.020
Panel Thickness - Inches	0.345	0.365	-	0.345
	0.345	0.370	-	0.345
Apparent Density-lbs/ft ³	30.9	27.8	-	24.0
Compressive Strength-psi				
Flatwise	-	-	-	-
Edgewise	1175 1035 1160 1095	1060 1055 1205	870	800 675 830 710
Flatwise Flexural Strength-psi, Ultimate	5010 5250	6610 6780	- -	3690 3760
Proportional	2890 2470	5920 5510	- -	3340 3300
Modulus of Elasticity psi X10 ⁶		0.813 0.770	- -	0.515 0.533

TABLE 3
WAFFLE CORE SANDWICH TEST DATA

Property	Panel Number						
	22	24	15	23	10	14	11
Faces - Glass Fiber Mat, X-30,000							
Core - Knit Cotton Cloth, C-126							
Adhesive - Plycozite							
Face Thickness - Inches	0.045	0.035	0.030	0.030	0.025	0.025	0.020
Panel Thickness - Inches	-	0.390	0.362	-	-	0.361	0.347
	-	0.390	0.361	-	-	0.361	0.347
Apparent Density - lbs/ft ³	-	28.9	-	-	-	-	23.6
Compressive Strength - psi	1116	-	-	459	875	-	-
Flatwise	706	-	-	395	569	-	-
Edgewise	-	1000	1080	-	-	550	610
	-	800	1530	-	-	920	950
	-	1565	1270	-	-	1420	810
	-	1425	1000	-	-	2065	1410
Flatwise flexural Strength-psi	-	5660	5140	-	-	4260	3650
Ultimate	-	7390	4000	-	-	3590	3420
Proportional	-	3770	2980	-	-	2890	2520
	-	4120	2530	-	-	2460	2010
Modulus of Elasticity	-	0.423	0.428	-	-	0.441	0.345
X10 ⁶	-	0.495	0.394	-	-	0.461	0.353

TABLE 4

WAFFLE CORE SANDWICH TEST DATA

Faces - Fiberglass Cloth, ECC-112
 Core - Knit Cotton Cloth, C-126
 Adhesive - Flycosite

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Property	Panel Number						
	12	17	18	21	13	16	20
Face Thickness - Inches	0.030	0.030	0.030	0.030	0.020	0.020	0.020
Panel Thickness - Inches	-	0.360 0.355	-	0.350 0.350	-	0.340 0.345	0.350 0.355
Apparent Density - lbs/ft ³	644 878	-	890 1250	-	944 1406	-	-
Compressive Strength - psi	-	355 720 950 610	-	885 805	-	510 570 460	690 675 485
Flatwise Flexural Strength Ultimate - psi	-	4010 3960	-	4730 5280	-	2440 3620	4150 5170
Proportional - psi	-	2600 2470	-	2010 3840	-	1720 3170	2950 2500
Modulus of Elasticity X10 ⁶ - psi	-	0.731 0.742	-	0.610 0.602	-	0.569 0.492	0.517 0.579

TABLE 5

PROPERTIES OF HONEYCOMB SANDWICH PANEL*

Thickness	0.410" - 0.440"
Core Material	ECC-112 Fiberglass cloth honeycomb
Core Cell Size	3/16" Diameter
Face Material	ECC-112 HT Fiberglass Cloth
Face Thickness	0.035"
Apparent Density of Sandwich	22.5 lbs/cu.ft.
Compressive Strengths	
Flatwise	405 psi (5 specimens)
Edgewise	1187 psi (5 specimens)
Flexural Strengths	
Ultimate	6410 psi (5 specimens)
Proportional	3184 psi (5 specimens)
Modulus in Flexure	678 (3 specimens)

* Probably produced by Plaskon in late 1944.

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TABLE 6

COMPARISON OF BEST WAFFLE PANEL
WITH
HONEYCOMB PANEL

<u>Property</u>	<u>Strength Weight Ratios*</u>	
	<u>Honeycomb Sandwich Panel</u>	<u>Waffle Sandwich Panel No. 9</u>
Compressive Strength		
Edgewise	52.8	40
Flexural Strength		
Ultimate	285	241
Flexural Strength		
Proportional	142	205
Modulus of Elasticity		
in Flexure - psi	0.690 x10 ⁶	0.791 x10 ⁶

* Strength-Weight Ratio = $\frac{\text{pounds per square inch}}{\text{pounds per cubic foot}}$

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TABLE 7

Known Specific Uses for Sandwiches in Aircraft and Missile Parts

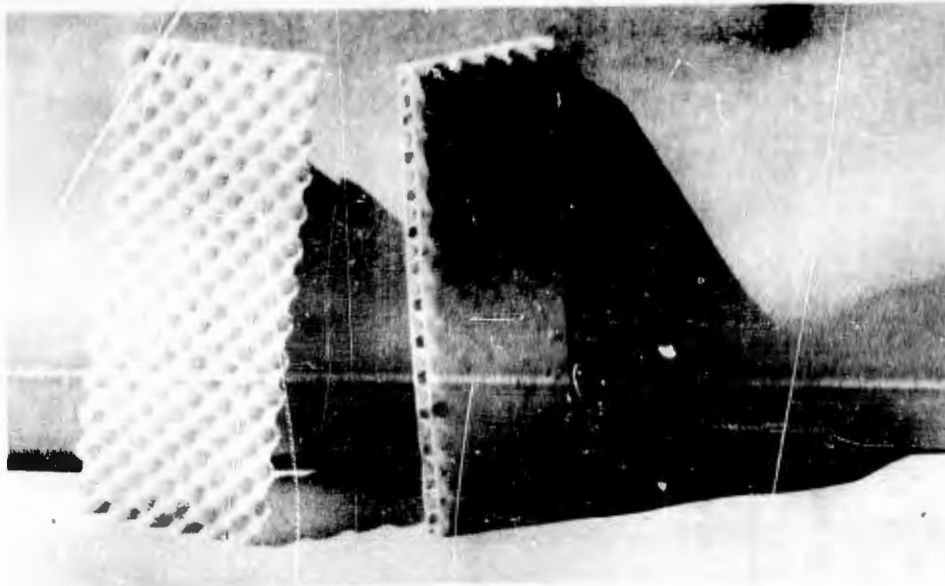
Aileron tabs and ailerons
Air-deflectors
Antenna Housings (radomes)
Bulkhead panels, structural and fire retardant
Cabinets
Collapsible tables
Containers for precooked food
Data cases
Doors
Flooring
Food-cooler
Furniture
Air frame sections
Jettison tanks
Instrument cases
Navigation tables
Nose Cones
Pontoons
Ribs and other reinforcing members
Tail Cones
Transit cases
Wing structures

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TABLE 8

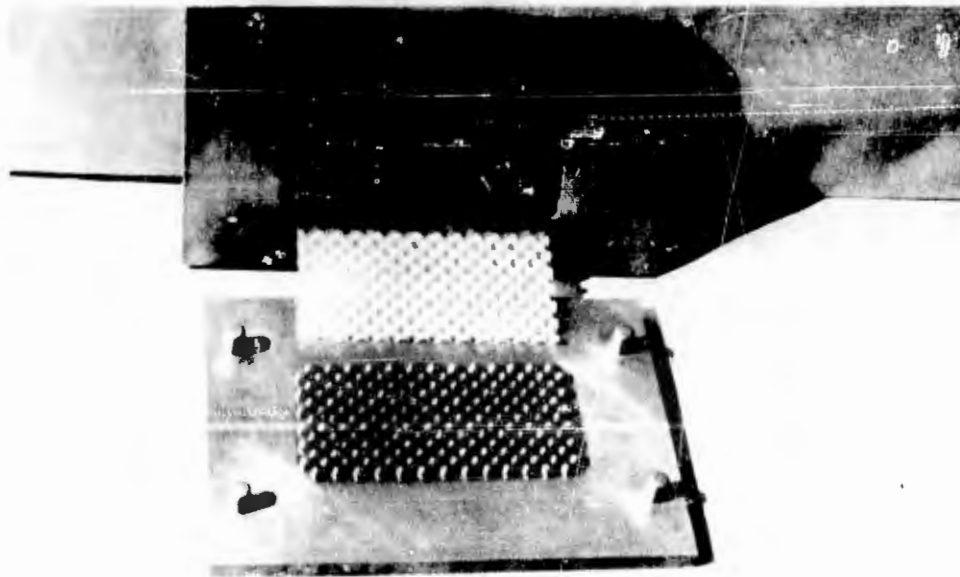
<u>Important Parameters</u>	<u>Applications</u>
Flexural Strength and Stiffness	Wing Structures: Ailerons
Flatwise Compressive Strength and Stiffness	Flooring - (Heel Impact and Distributed Loads.)
Flatwise Compressive Resilience	Solid Blast Protective Flooring
Edgewise Compressive Strength and Stiffness	Bulkhead panels
Torsional Strength and Stiffness	Ailerons; Wing and Fuselage Structures
Mechanical Damping	Ailerons; Wing and Fuselage Structures
Microwave Transmission	Antenna Housings; Microwave Lenses
Heat Transfer from Internal Fluids	Antenna Housings; Wing Leading Edges; Wall Sections, Heat Exchangers.
Strength-Weight Ratios	All Aircraft and Shipboard Applications

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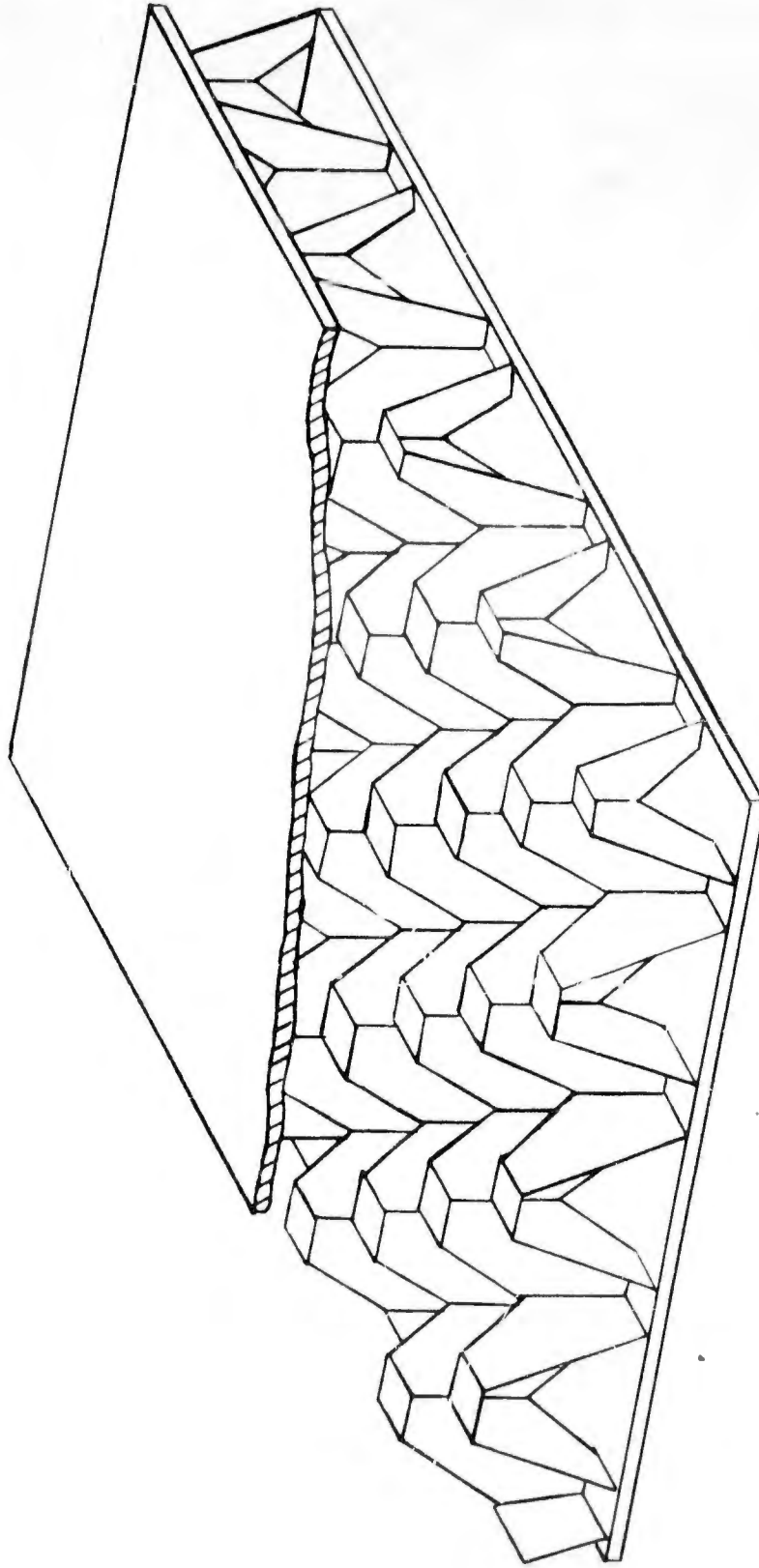
WAFFLE CORE SHEET AND FINISHED
SANDWICH PANEL

FIG. 1



WAFFLE CORE SHEET AND EXPERIMENTAL
STEEL MOLD

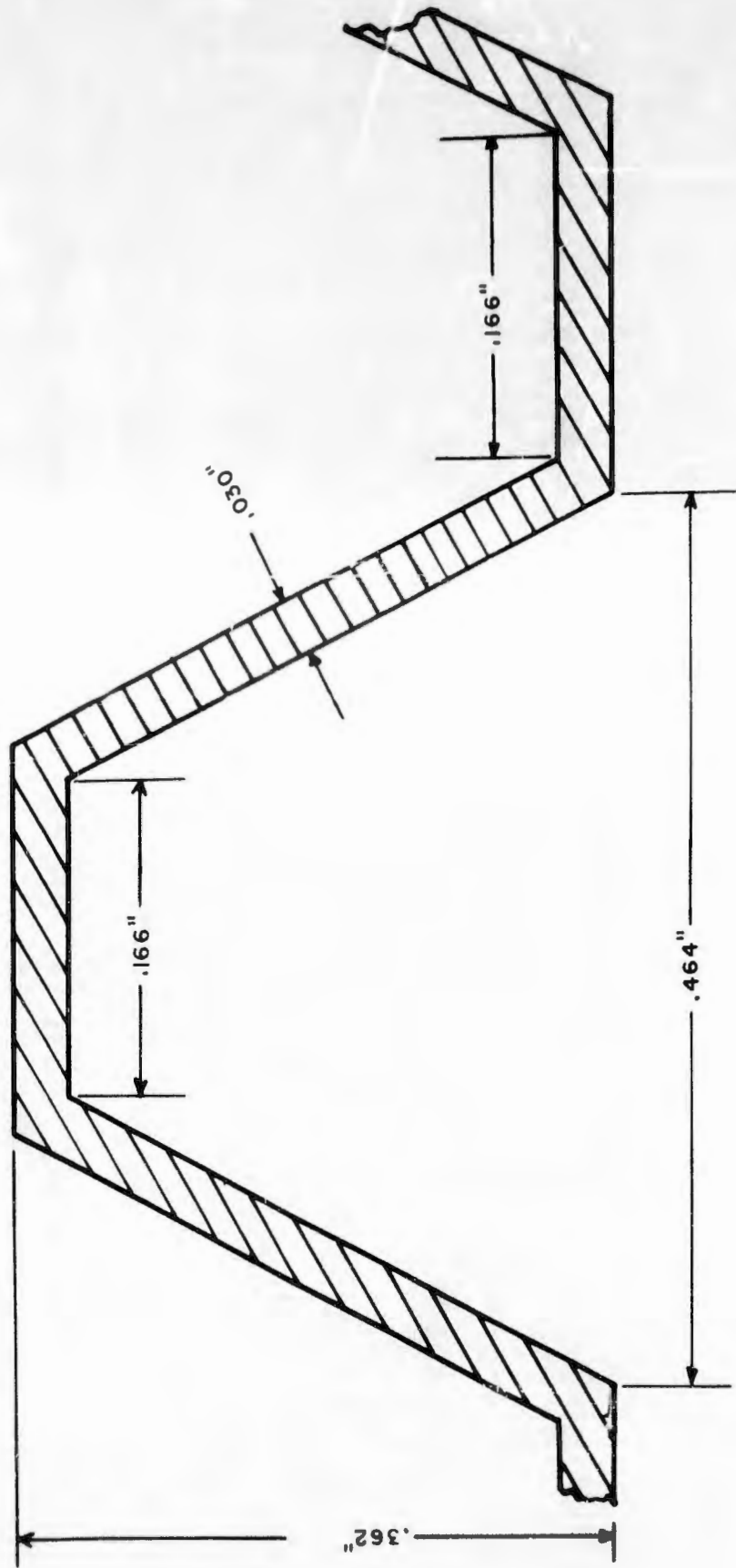
FIG. 2



CUT-AWAY VIEW OF WAFFLE CORE SANDWICH PANEL

FIG. 3

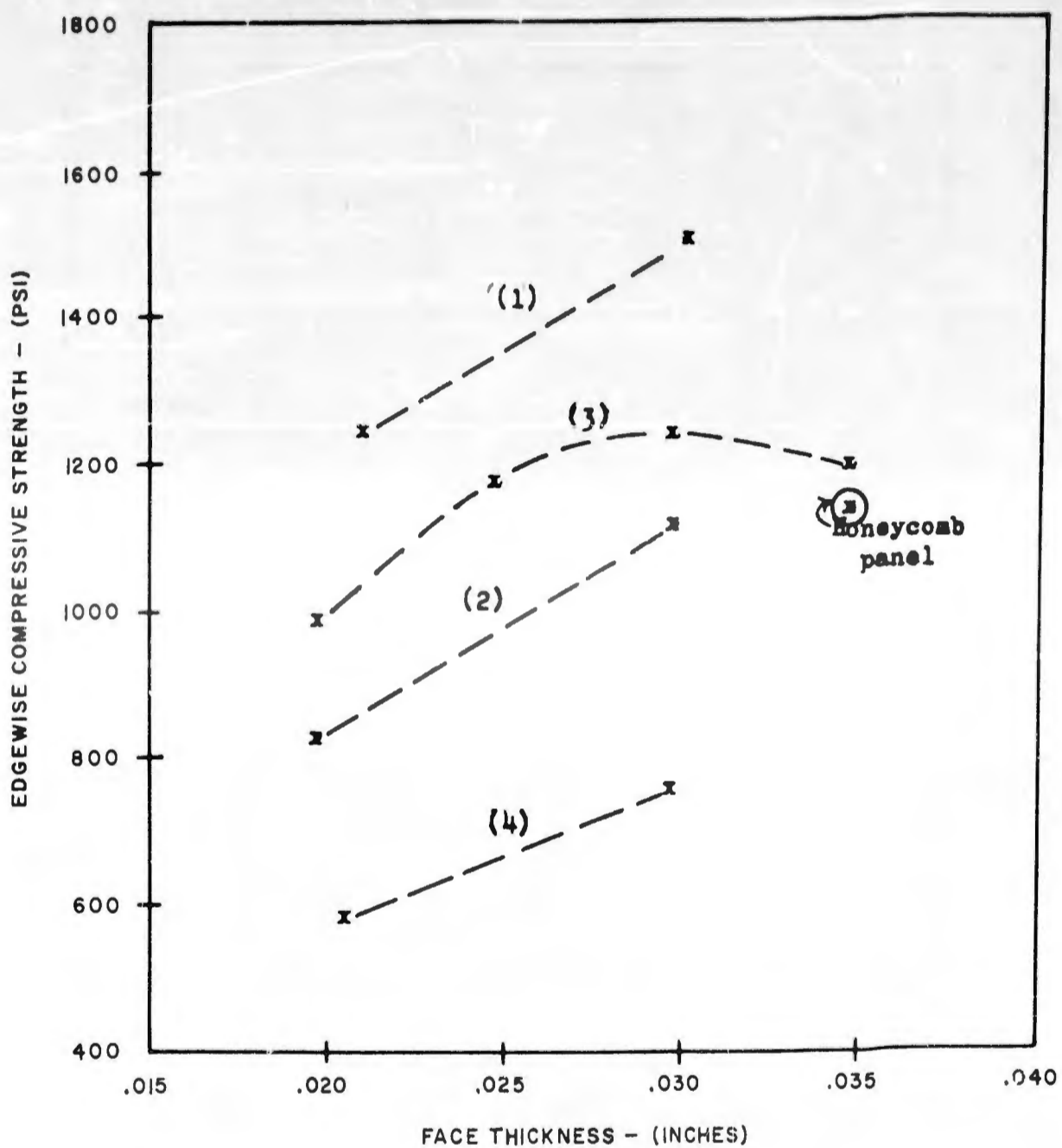
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CROSS SECTIONAL DIMENSIONS OF EXPERIMENTAL
WAFFLE CORE MATERIAL

FIG. 4

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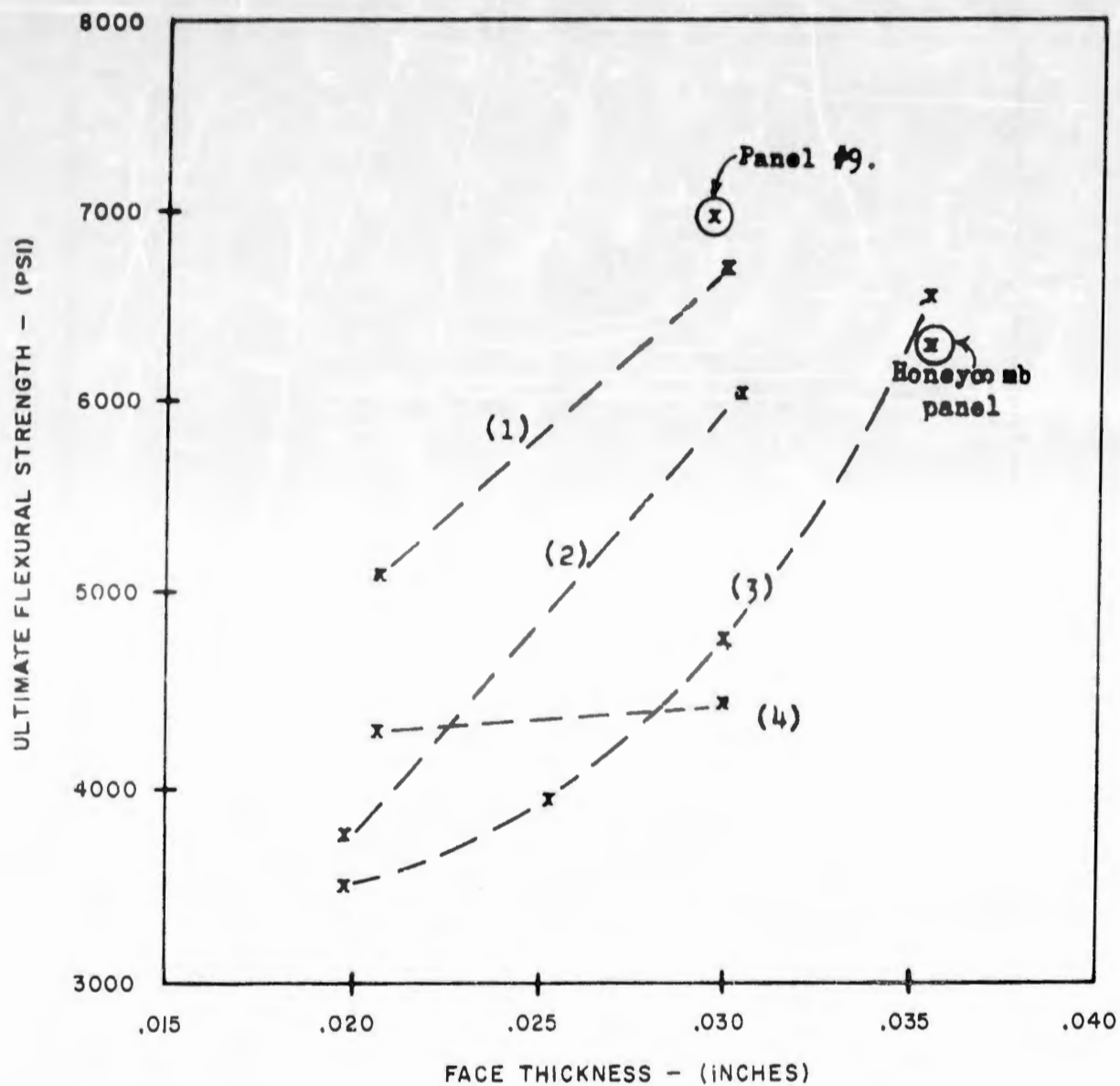


- Note: (1) Glass mat cores with glass mat faces
(2) Glass mat cores with glass cloth faces
(3) Knit cotton cores with glass mat faces
(4) Knit cotton cores with glass cloth faces

EDGEWISE COMPRESSIVE STRENGTH

FIG. 5

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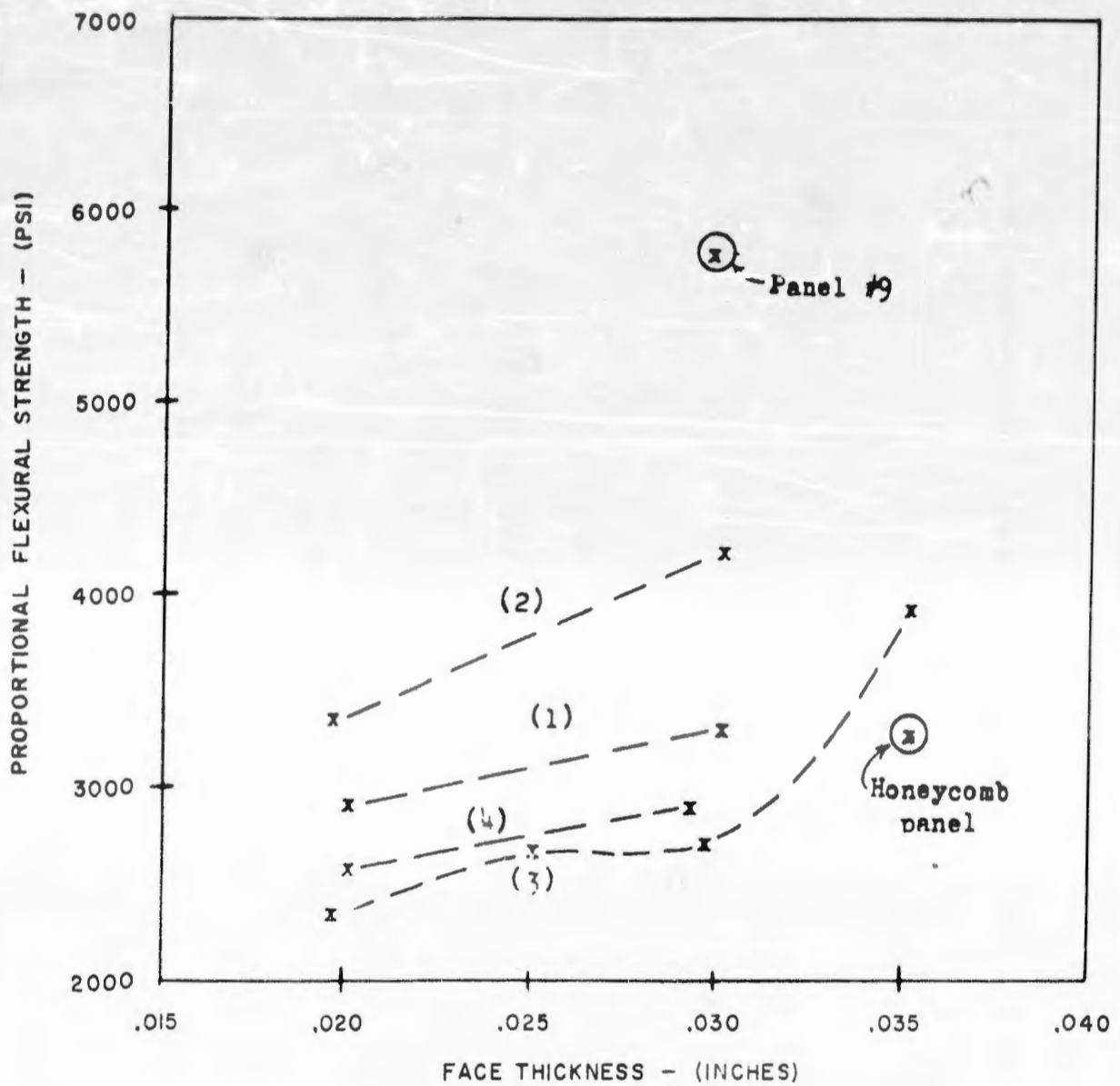


- Note: (1) Glass mat cores with glass mat faces
(2) Glass mat cores with glass cloth faces
(3) Knit cotton cores with glass mat faces
(4) Knit cotton cores with glass cloth faces

ULTIMATE FLEXURAL STRENGTH

FIG. 6

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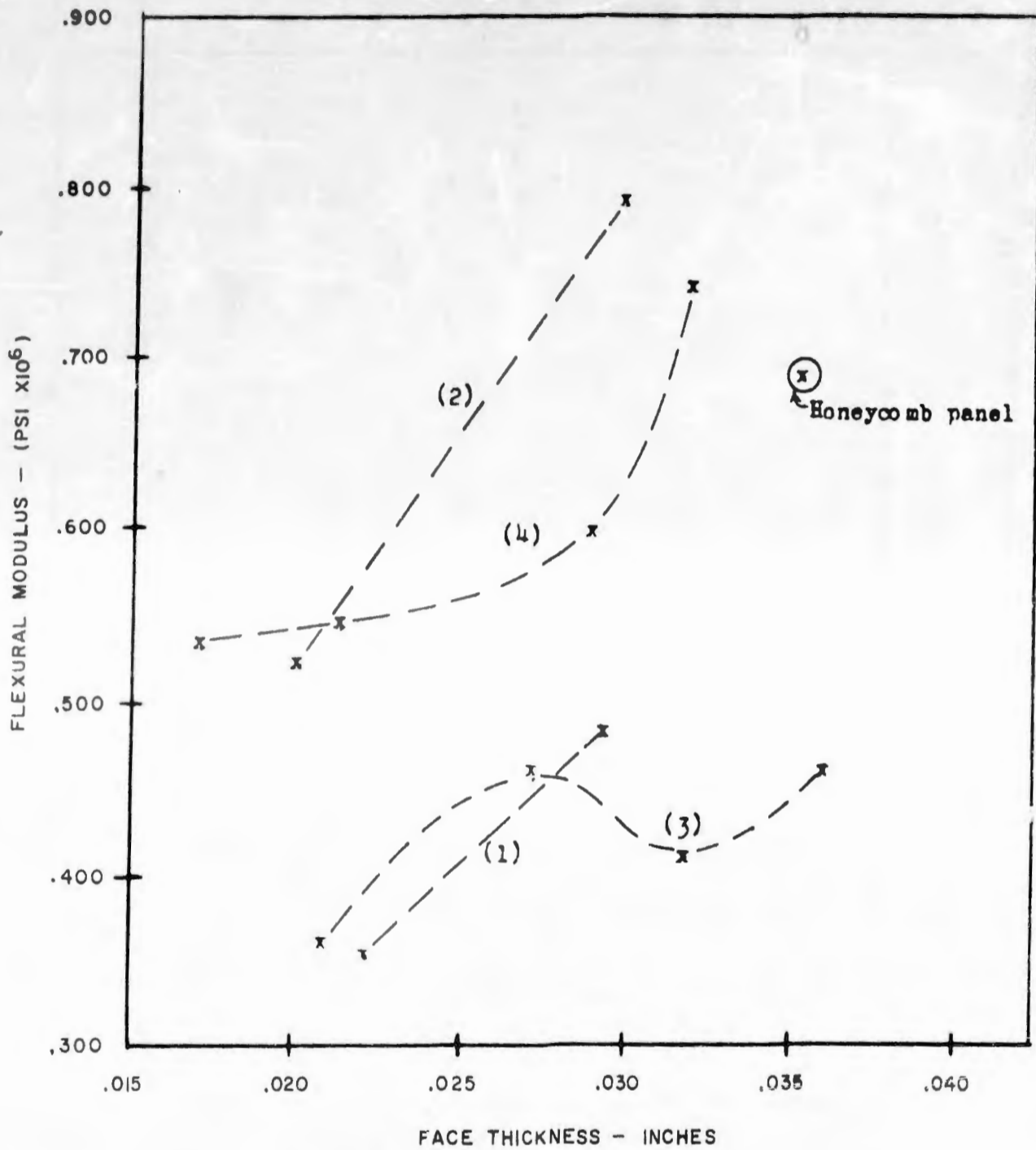


- Note: (1) Glass mat cores with glass mat faces
(2) Glass mat cores with glass cloth faces
(3) Knit cotton cores with glass mat faces
(4) Knit cotton cores with glass cloth faces

PROPORTIONAL FLEXURAL STRENGTH

FIG. 7

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- Note: (1) Glass mat cores with glass mat faces
(2) Glass mat cores with glass cloth faces
(3) Knit cotton cores with glass mat faces
(4) Knit cotton cores with glass cloth faces

MODULUS OF ELASTICITY IN FLEXURE

FIG. 8

TYPICAL POSSIBLE COMPOSITE SANDWICH STRUCTURES

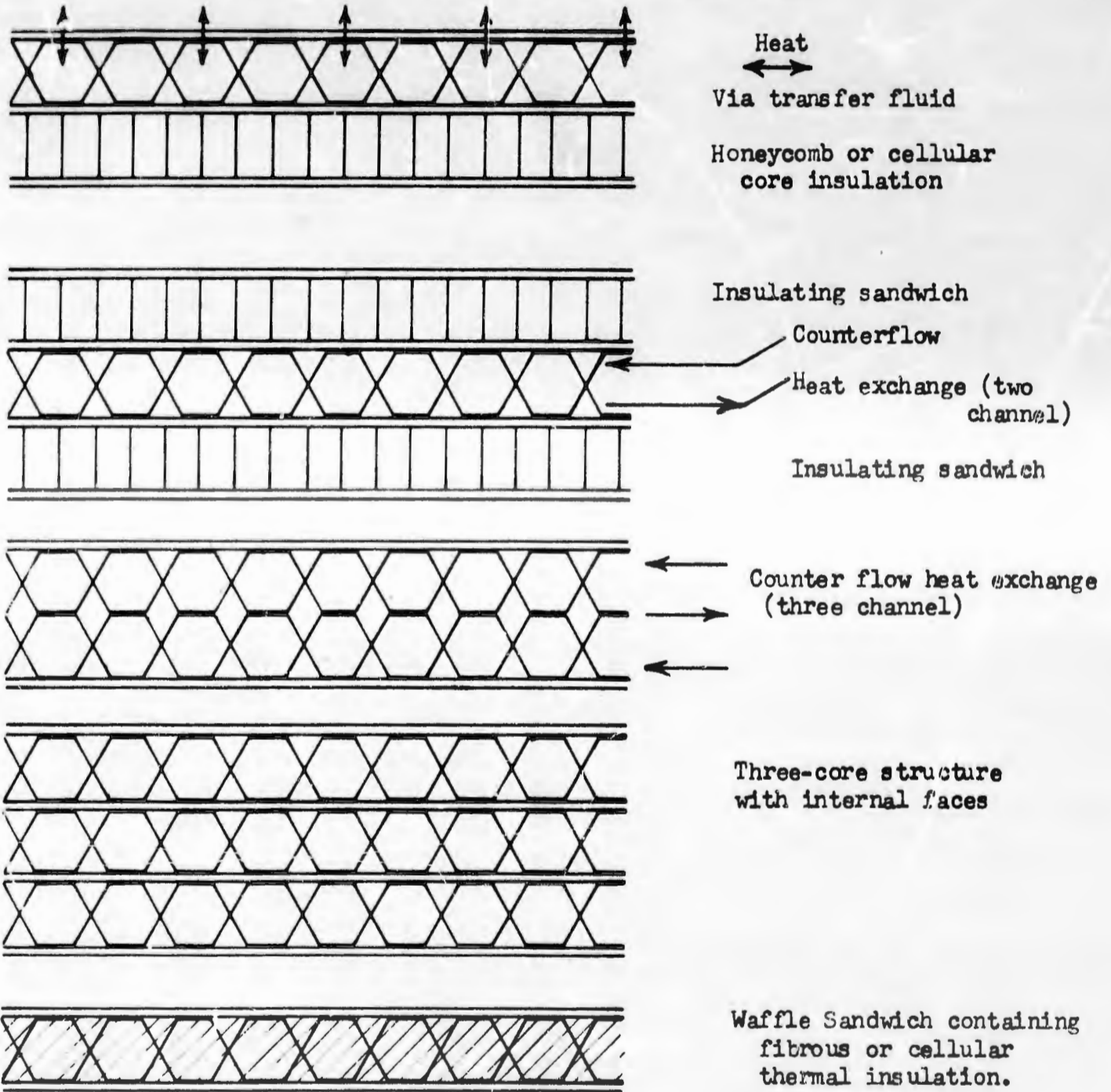


Figure 9

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