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COMPOSITE LATTICE STRUCTURE

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September 1975

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16. Abstract

A lattice type structural panel concept is described which exploits the unidirectional character of filamentary advanced composite materials. This lattice has potential for applications where stiff lightweight structures are needed such as large area panels for space satellites. Formulae are presented to calculate the panel weight and plate bending stiffness. This analysis indicates that structures with significantly lighter weight than conventional minimum gage sandwich construction can be fabricated. A suggested fabrication procedure is also presented along with photographs of some typical panels.

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INTRODUCTION

Contemporary and future aerospace vehicle requirements continue to provide challenges to the structural designer for reducing structural weight. In aircraft, fuel economy is putting a premium on structural weight (ref. 1) while in spacecraft there are anticipated needs for very large area space structures (ref. 2) that will severely tax the load carrying capability of any conceivable booster system. Relatively recent advances in filamentary composite materials (ref. 3) have provided the structural designer improvements of a factor of 2 to 3 in strength to density ratios and a factor of 3 to 4 in modulus to density ratios when compared with commonly available metals. To take full advantage of these improvements, however, structural design concepts must be originated which consider from the outset, the highly unidirectional nature of the advanced filamentary composite materials.

In the present paper a lattice type structural panel is described in which an attempt is made to fully exploit the unidirectional characteristics of filamentary composites. The main motivation for the development of such a concept is the requirement for large area space structures which are designed on the basis of stiffness rather than strength. Although sandwich construction is very efficient from a weight standpoint for moderate to heavily loaded structures, severe weight penalties result for very lightly loaded sandwich structures due to minimum gage constraints on skin thickness, glue weight and core density. In an attempt to circumvent these minimum gage problems a very sophisticated electroformed, hollow core aluminum structure was developed in reference 4. The concept developed in reference 4 has a resultant weight per unit area that is impressively low, however, the cost for producing such structures may be very high. The lattice concept of the present paper has the potential of being as low or even lower in weight per unit area than the electroformed concept and should be at least an order of magnitude cheaper to produce.

Although the lattice concept was originally conceived for stiffness critical structures, it also appears to have weight advantages for structures which are designed by moderate loads. In this paper a description is given of the concept, and the construction techniques are discussed, Carpet plots are presented which give the weights and bending stiffnesses of lattice panels for a wide range of geometric variables and a weight comparison is made with sandwich panels. The material system considered is graphite/epoxy and the lattice network is taken as isotropic. For specific applications other composite material systems could well be appropriate and the geometry of the lattice network could be tailored to suit the stiffness or loading requirements.

SYMBOLS

A	area
a	width of lattice strips (see sketch a)
D	plate bending stiffness, see equation 5
E	elastic modulus
ℓ	spacing of lattice strips (see sketch a)
t	thickness
W	mass
ν	Poisson's ratio
ρ	density

Subscripts

1,2	indicate size relation, see equation 9
a	adhesive
c	core
e	effective or smeared
f	sandwich face sheets
p	total plate
t	composite material tape

Basic Concept

The basic composite lattice concept is shown in Figure 1. It consists of a regular geometrical arrangement of strips of advanced composite material on an open grid honeycomb core. It resembles a highly redundant truss network which genarally have high structural efficiency. The lattice concept relieves designers of weight penalties imposed by minimum gage requirements because two additional parameters are introduced. These parameters are the spacing and width of the lattice strips. The lattice network shown in Figure 1 has a one ply, (0, $\pm$ 60) pseudo-isotropic face sheet.

Other concepts of a similar nature can also be considered such as the one shown in Figure 2. The pattern shown in this sketch is also a pseudo-isotropic laminate of (0, ± 45, 90) orientation. Although both concepts shown have pseudo-isotropic face sheets, composite lattice structures are not limited to isotropic type laminates. Panel design may be tailored to suit a specific application by using multiple thickness laminates in any specific direction or on selected strips. Some typical examples are shown in Figure 3 for the (0, ± 60) face sheet. In addition, the (0, ± 45, 90) pattern could have some diagonal strips (± 45) omitted or a combination of multiple thickness laminates and omitted diagonal strips and still maintain a regular network pattern as shown in Figure 4. For applications requiring the structure to support a low pressure lateral load a film could be bonded to one face sheet as in Figure 5a or one side of the panel could be a full multi-ply laminate (Figure 5b) with the opposite side and core of lattice construction. The sketches shown in Figure 3, 4, and 5 illustrate the design latitude available using the composite lattice concept.

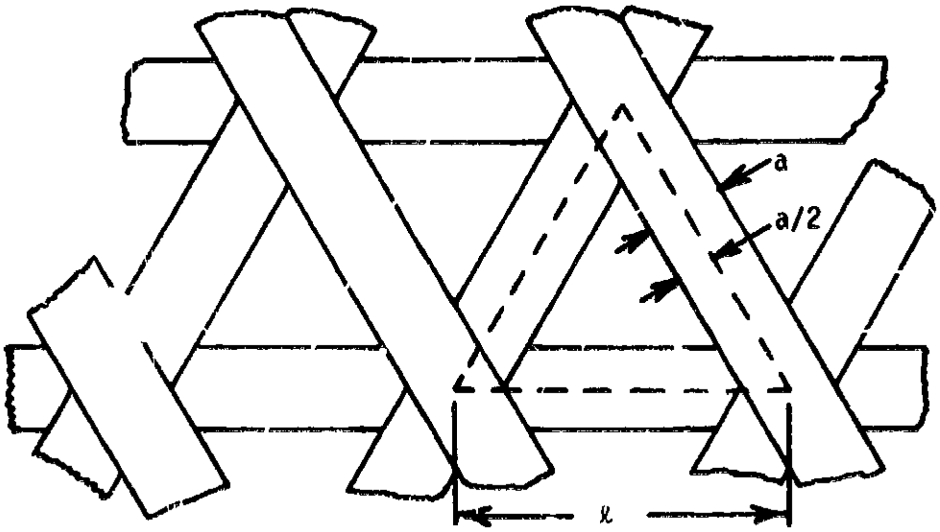
Some of the design parameters for lattice structure are given in Table 1. These parameters fall into two groups, those associated with the lattice face sheets and those related to the honeycomb core. By appropriate selection of the design parameters, the weight, strength and stiffness of a panel can be selectively tailored.

The composite lattice panel concept was conceived for lightly loaded applications such as space structures where stiffness rather than strength is the predominant design parameter. However, it may have applications for more moderately loaded structures. Also, due to the high degree of redundancy and diagonal supports (truss framework) the concept may have applications where fail-safety is considered.

ANALYSIS

In the previous section two concepts were proposed. The first was (0, ± 60) and the second was a (0, ± 45, 90) face sheet lattice. Although both are pseudoisotropic laminates and are viable lattice panel candidates, only the (0, ± 60) is examined in this section. Furthermore, only this configuration with uniformly spaced single thickness laminates is considered.

Mass - The mass of composite lattice panels can be determined using a typical triangular element as shown in sketch a.



Sketch a - Typical triangular element

Considering only the material within the dashed line the mass of a typical triangular element can be found to be

$$W \approx 3\, a\ell\, \rho_t t_t + (\rho_c t_c + 2\, \rho_a t_a)\left(\frac{3}{2}\, a\ell - \frac{3\sqrt{3}}{4}\, a^2\right) \qquad 1$$

The area for this same element is given by

$$A = \frac{\sqrt{3}}{4}\, \ell^2 \qquad 2$$

Therefore the unit mass of a panel is given by

$$W/A = 2\sqrt{3}\ \frac{a}{\ell}\ (2\ \rho_t t_t + \rho_c t_c + 2\ \rho_a t_a) - 3(\frac{a}{\ell})^2\ (\rho_c t_c + 2\ \rho_a t_a) \qquad 3$$

These equations apply only when the spacing $\ell > a\sqrt{3}$. If the spacing $\ell \leq a\sqrt{3}$, the lattice will have no triangular cutouts in the honeycomb core or adhesive, however, it will also not have adjacent strips of composite material touching as if a full three ply laminate. For this configuration the unit mass is given by

$$W/A = 4\sqrt{3}\,\frac{a}{\ell}\,\rho_t t_t + \rho_c t_c + 2\rho_a t_a \qquad 4$$

where

$$\frac{2a}{\sqrt{3}} \leq \ell \leq a\sqrt{3}.$$

When the spacing becomes equal to $\frac{2a}{\sqrt{3}}$ the lattice is reduced to standard sandwich construction with face sheets of three continuous lamina.

Shown in Figure 6 is the unit mass of lattice panels as a function of spacing (ℓ) for two thicknesses of tape material. The 0.0055 in. thick tape is the standard commercial prepreg material while the 0.003 in. thick material is also commercially available but is not as commonly used. The properties of all materials used to calculate the structural mass are given in Table 2 and are considered to be representative of available commercial products. It can be noted that with a large spacing (ℓ) a very low mass structure can be fabricated using the lattice concept. However, as the spacing is reduced the structural mass increases to the mass of standard sandwich construction which is approximately 0.25 and 0.37 lbs/ft^2 for the two thicknesses of tape considered. It should also be observed that if design requirements dictate a specific cross sectional area of material, then a thicker tape rather than a wider lattice strip (a) will yield the lower mass structure because the wider lattice strip has more honeycomb weight included.

<u>Plate Bending Stiffness</u> - The bending stiffness of sandwich structures can be calculated from the equation (reference 5)

$$D = \frac{E_f(t_p^3 - t_c^3)}{12\,(1 - \nu_f^2)} \qquad 5$$

when $E_f >> E_c$. If the lattice facings are considered to be smeared over the entire face sheet an effective face sheet thickness can be found to be

$$t_e = 2\sqrt{3}\ \frac{a}{\ell}\ t_t \qquad 6$$

Plate bending stiffness in terms of effective face sheet thickness can be determined by substituting

$$t_p = 2t_e + t_c \qquad 7$$

into equation 5 and expanding t_p^3. If $t_e << t_c$ then

$$D = \frac{E_f t_c t_e}{2\,(1-\nu_f^2)}\ (2t_e + t_c) \qquad 8$$

Bending stiffness as a function of strip spacing (ℓ) for several rib widths and two composite tape thicknesses is shown in Figure 7. These results were calculated using a core thickness of 0.2 inches and other material parameters given in Table 2. As the lattice spacing increases the stiffness decreases from that of conventional sandwich structure to lower values as one would expect from an examination of equation 8.

A carpet plot giving the mass of a panel as a function of plate bending stiffness for sandwich panels and lattice panels having various ratios of a/ℓ is shown in Figure 8. Also shown on the figure are curves indicating constant honeycomb core depth. Based on these calculations, lattice construction offers significant weight saving potential when compared with sandwich panels of equal bending stiffness. For a given ratio of a/ℓ and tape thickness, bending stiffness increases due to increases in core depth. However, for very thick cores the mass can be reduced by increasing the thickness of the face sheet instead of the thickness of the core. The point at which face sheet thickness should be increased instead of increasing the thickness of the core can be determined from the simultaneous solution of the equations for mass and stiffness. The relation between tape and core thickness has been found to be

$$t_{2c} = t_{1c}\sqrt{\frac{t_{1t}}{t_{2t}}} \qquad 9$$

$$t_{1c} = 4\rho_t\ (t_{2t} - t_{1t})/\rho_c\ (2 - \sqrt{3}\ \ a/\ell)\ (1 - \sqrt{\frac{t_{1t}}{t_{2t}}}) \qquad 10$$

where $t_{2t} > t_{1t}$

Therefore, all design variables need be considered when examining requirements for a particular application.

Fabrication

Composite sandwich lattice can be fabricated from commonly available materials and adhesive systems. The following discussion suggests one method of fabricatic , however, many other methods, or variations of the proposed method are possible.

Face Sheets.- The face sheets are fabricated from unidirectional preimpregnated tape that is cut into strips of the desired width. The strips are laid in a mold machined from aluminum and overcoated with a release agent. A machined mold such as the one shown in Figure 9 permits accurate alignment and positioning of the tape with minimum effort.

Honeycomb Core.- The triangular pattern in the honeycomb core may be removed either before or after bonding to the face sheets. If they are removed before bonding care must be taken to accurately position the core on the lattice strips. If they are removed after bonding there is danger of damage to the faces when the core is being cut.

In order to remove the triangular sections from the core a novel cutter was devised. A photograph of this cutter is shown in Figure 10. The cutter is fabricated from aluminum with conventional single edge razor blades as the cutting edge. A spring loaded plunger foot in the center removes the triangular section from the cutter.

The panels fabricated to date have been made by precutting the honeycomb core. A special template designed for this purpose is shown in Figure 11 and a photo showing the template and cutter in use is shown in Figure 12. The template was fabricated from thin aluminum sheet stock and the grid pattern was cut on a numerical controlled milling machine.

Curing and Bonding Face Sheets.- Panels fabricated in this investigation were made by using the template and cutter to precut the honeycomb core. Silicon rubber blankets were also cut with the template and placed in the base of the mold. The composite material face sheets were then placed in the mold followed by the honeycomb core whose faces had been coated with an epoxy resin system to permit bonding to the core. The molds were closed and loaded with lead weights to get good contact pressure between the face sheet and the honeycomb. The total system was heated to a low temperature to cure the bonding resin. The low temperature also allowed the resin in the graphite to flow and give good joint compaction. The lattice was then removed from the mold, vacuum bagged and placed in an oven to cure the resin in the graphite. It was necessary to cure the graphite prepreg outside the aluminum mold due to the differential thermal expansion between the aluminum and the graphite composite. Molds machined from a material with low thermal expansion characteristics such as graphite or a ceramic would allow the lattice to be completely bonded and cured in the mold in one operation without damage. A completed panel fabricated by the method outlined above is shown in Figure 13. This panel has a strip width of 0.25 inch and a lattice spacing of 1.5 inches.

SUMMARY

Future space missions may require large area structures which are designed on the basis of stiffness rather than strength. Sandwich structures are generally very efficient, however, for lightly loaded applications severe weight penalties result from minimum gage constraints. A lattice type structural concept has been described which exploits the unidirectional character of filamentary composite materials while relieving the designer of conventional minimum gage considerations. Although conceived for stiffness critical structures, the concept may have weight advantages for structures designed by moderate loads or applications where fail-safety is important.

Formulae are presented to calculate both weight and plate bending stiffness of the lattice structure. Carpet plots which give the weight and bending stiffness for a wide variety of geometric variables are also presented. The composite material system considered is graphite epoxy and the lattice network is isotropic, however, the analysis may be modified to consider other material systems or nonisotropic networks where appropriate. A suggested fabrication procedure is described along with photographs of some typical panels.

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Table 1.- Lattice Design Variables

Lattice Component	Design Variable
Honeycomb Core	Density Thickness Shear Modulus
Face Sheet	Design Configuration Material Modulus Material Strength Strip Width Strip Thickness Strip Spacing
Adhesive	Density Bond Strength

Table 2.- Material Properties Used to Calculate Panel Mass and Stiffness Parameters

Component Material	Property
Honeycomb core	ρ_c = 3.0 lb/ft^3 t_c = 0.2 in
Graphite epoxy Face sheet*	t_t = 0.003 in ρ_t = 0.0563 lb/in^3 ν_f = 0.326 E_t = 1.96 x 10^7 psi E_f = 7.84 x 10^6 psi
Bonding Adhesive	ρ_a = 0.208 lb/in^3 t_a = 0.001 in

* See reference 6 for properties of graphite epoxy tape material.

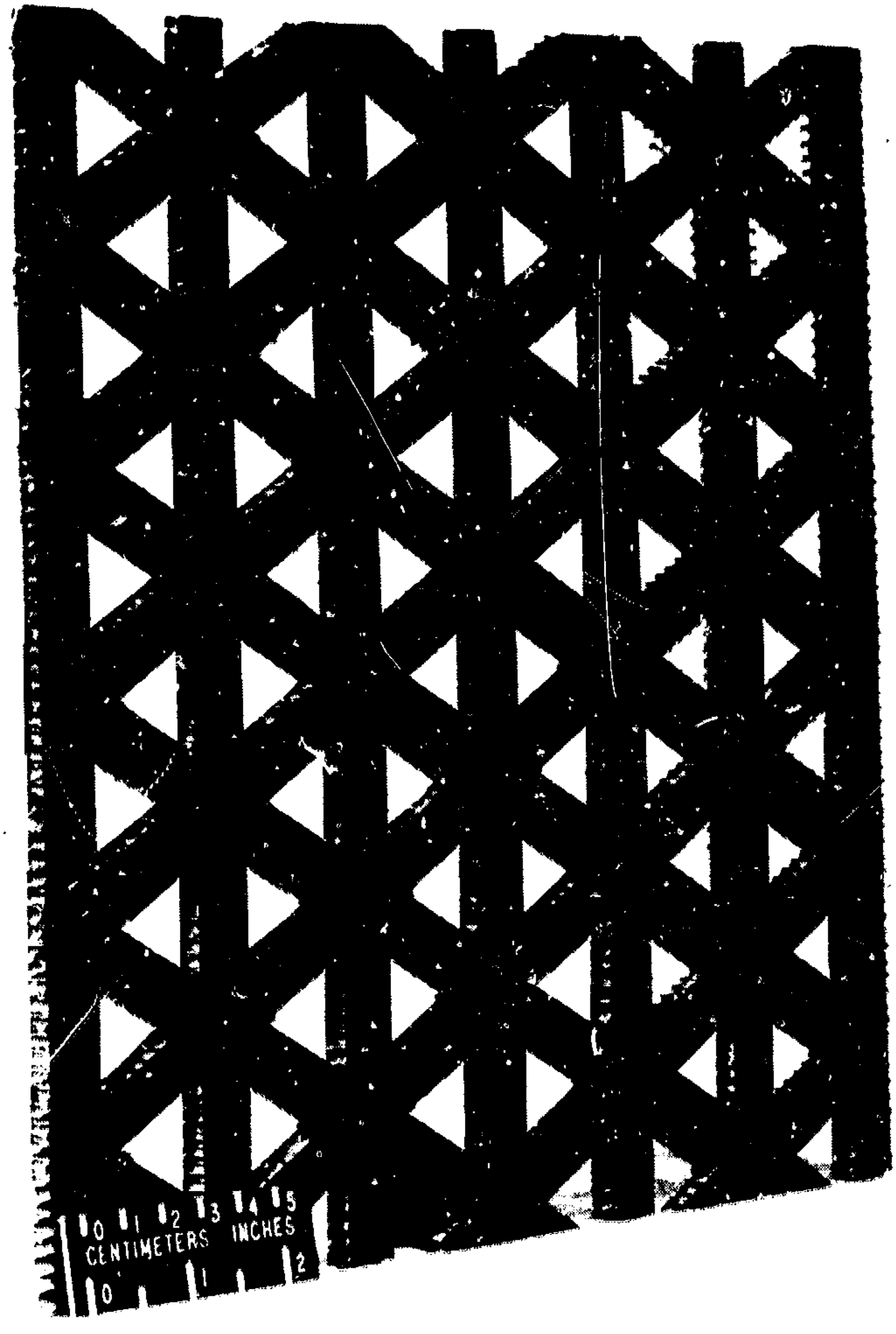


Figure 1. [illegible] faceshets.

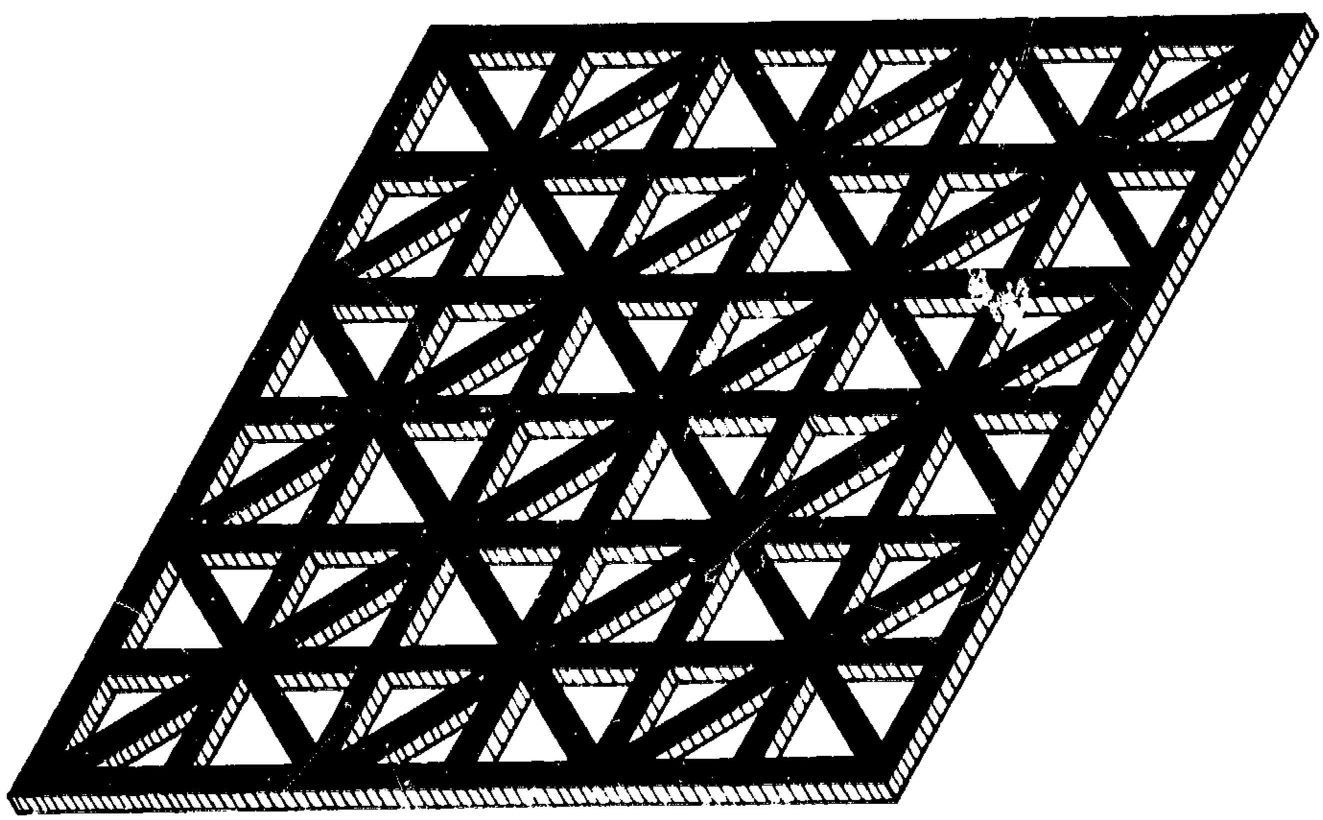
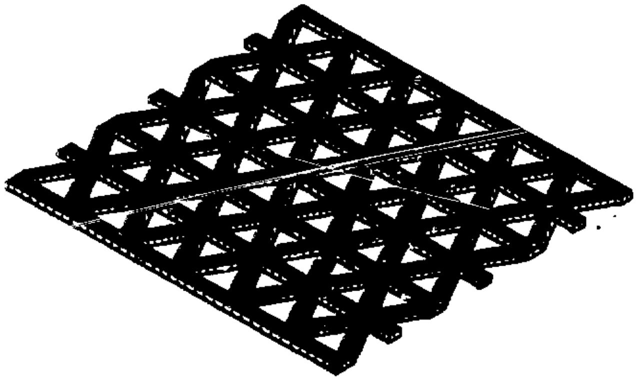
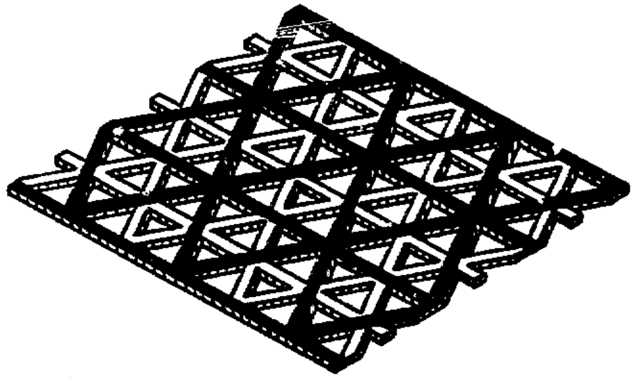


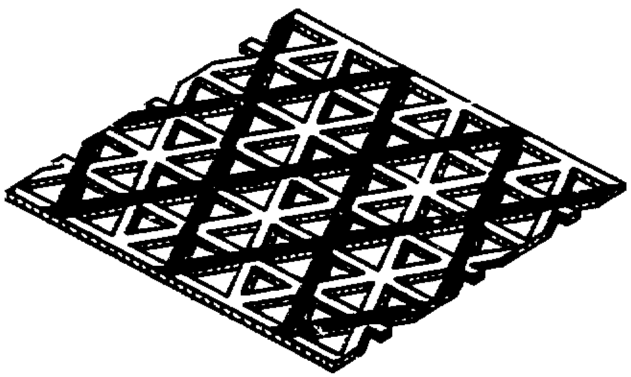
Figure 2.- Sketch of composite lattice panel with (0, ± 45, 90) face sheets.



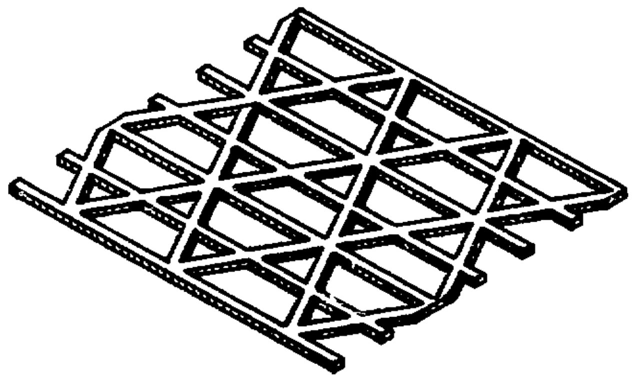
a. Multiple plies on all strips*



b. Multiple plies on selected strips*



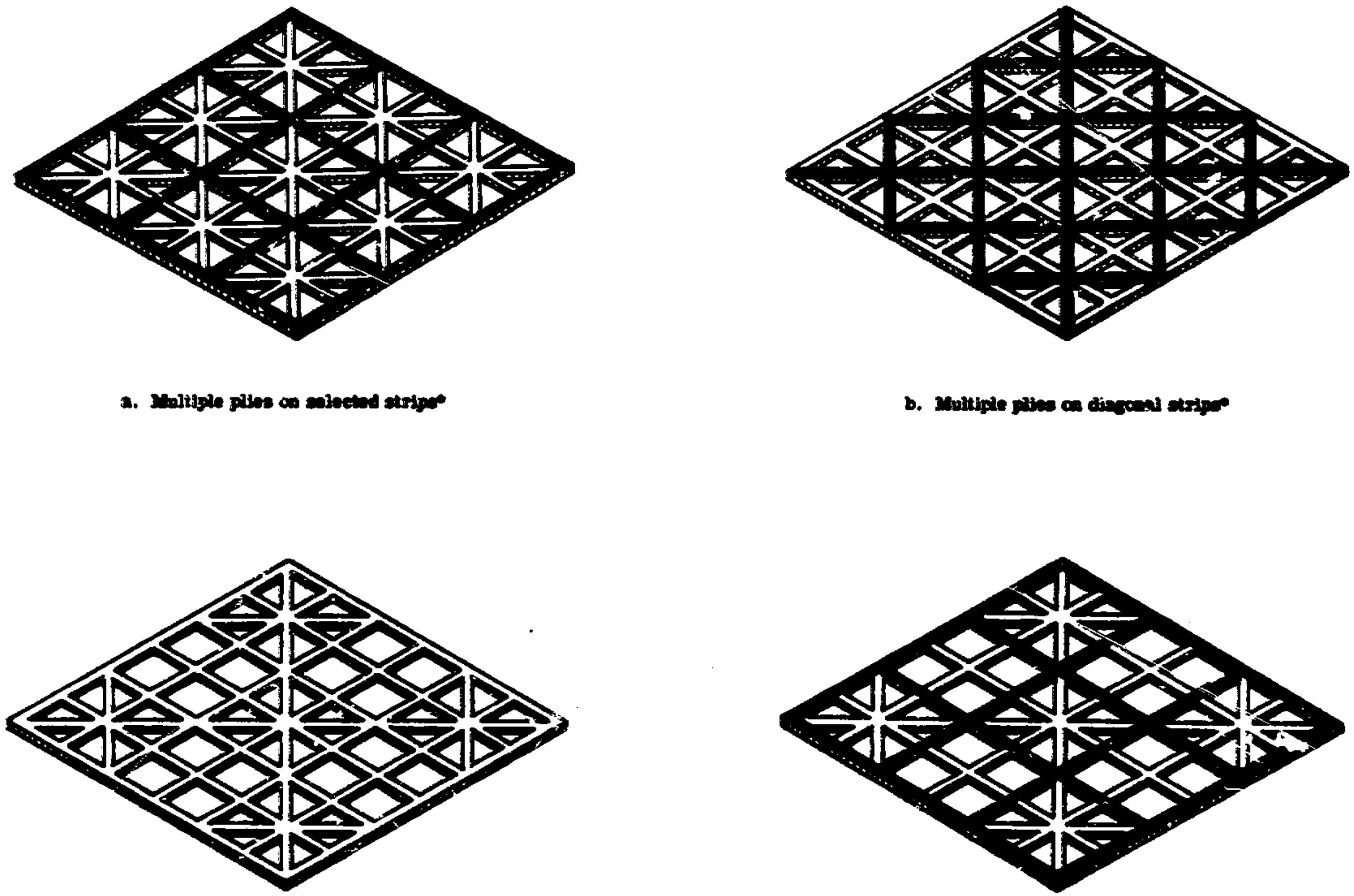
c. Multiple plies on diagonal strips*



d. Selected diagonal strips left out

* Dark strips indicate multiple plies

Figure 3.- Examples of tailoring the (0 ± 60) lattice face sheet to meet special design requirements.



a. Multiple plies on selected strips*

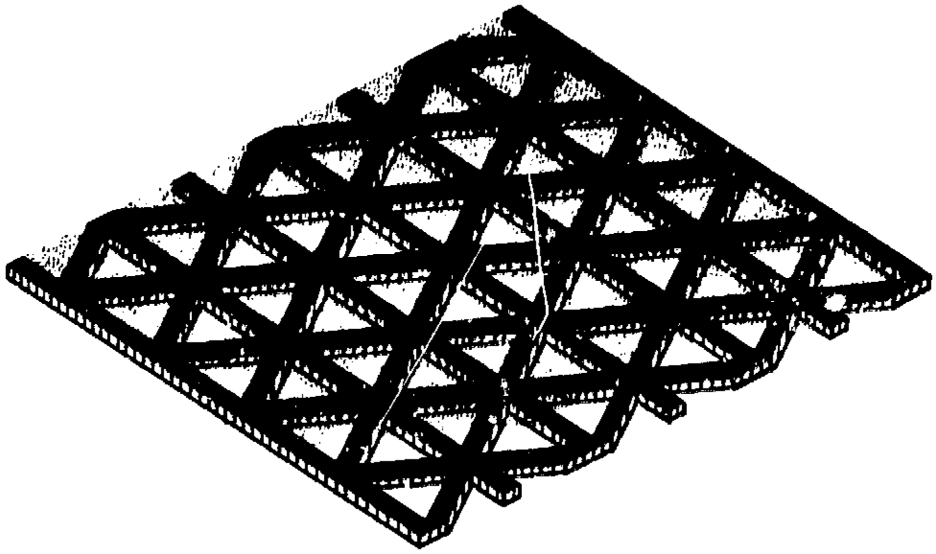
b. Multiple plies on diagonal strips*

c. Selected strips omitted

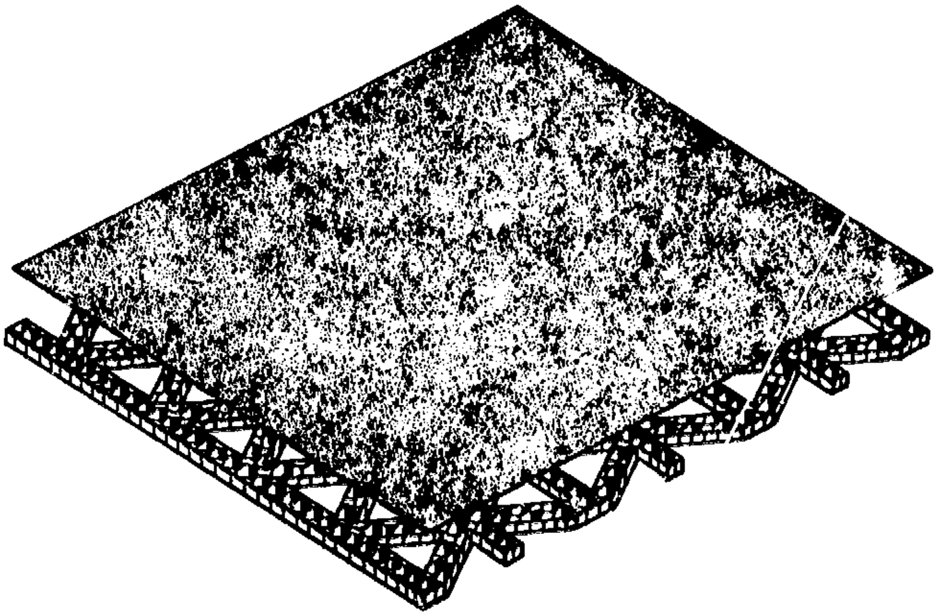
d. Combination of multiple plies and omitted strips*

* Dark strips indicate multiple plies

Figure 4.- Examples of tailoring the $(0 \pm 45, 90)$ lattice face sheet to meet special design requirements.



a. Composite lattice with bonded plastic film



b. Lattice with multiply laminate face sheet

Figure 5.- Sketches illustrating possible modification to the lattice face sheet to support pressure or other distributed panel loads.

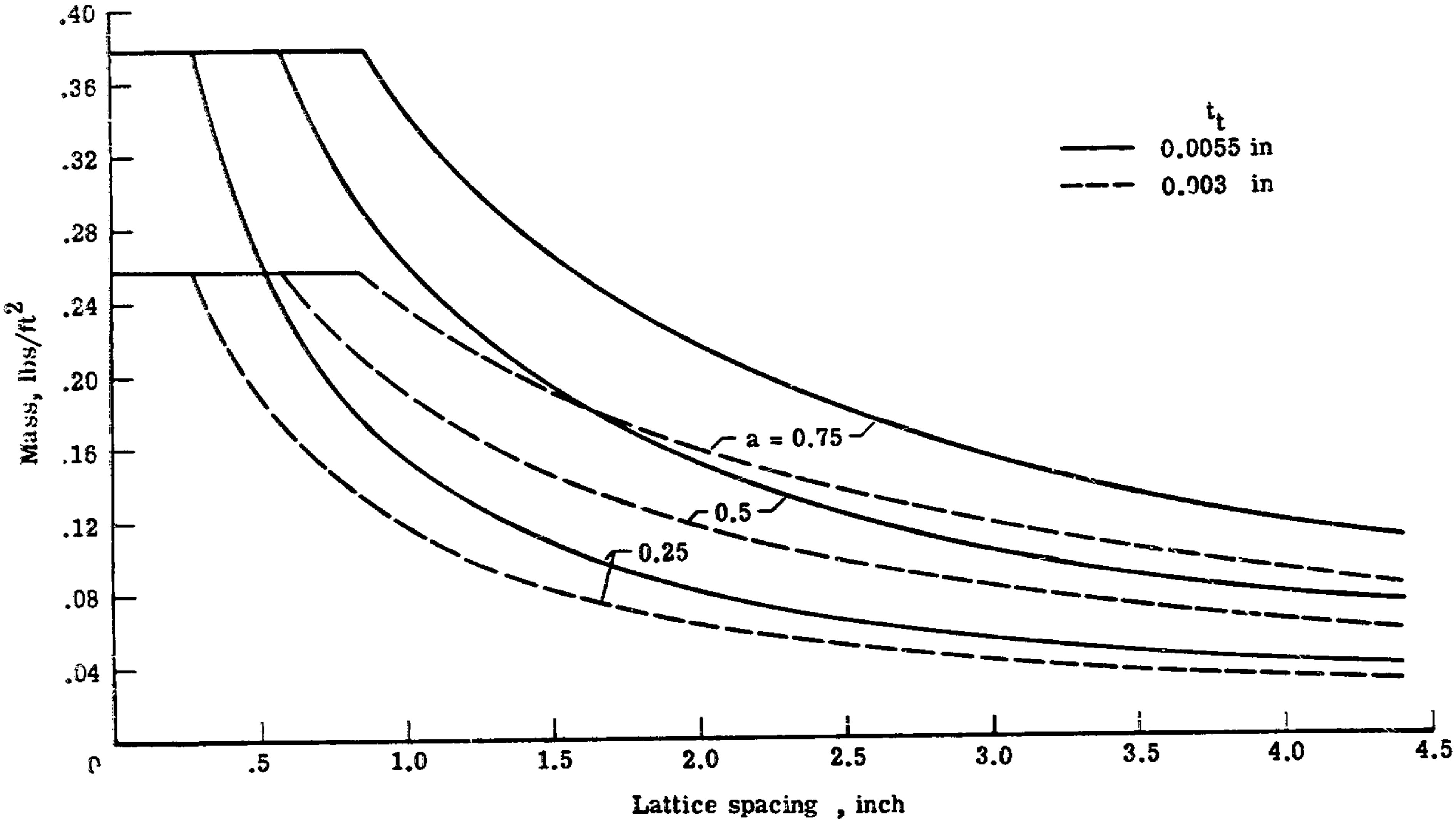


Figure 6.- Mass of lattice panels based on properties of commonly available materials.

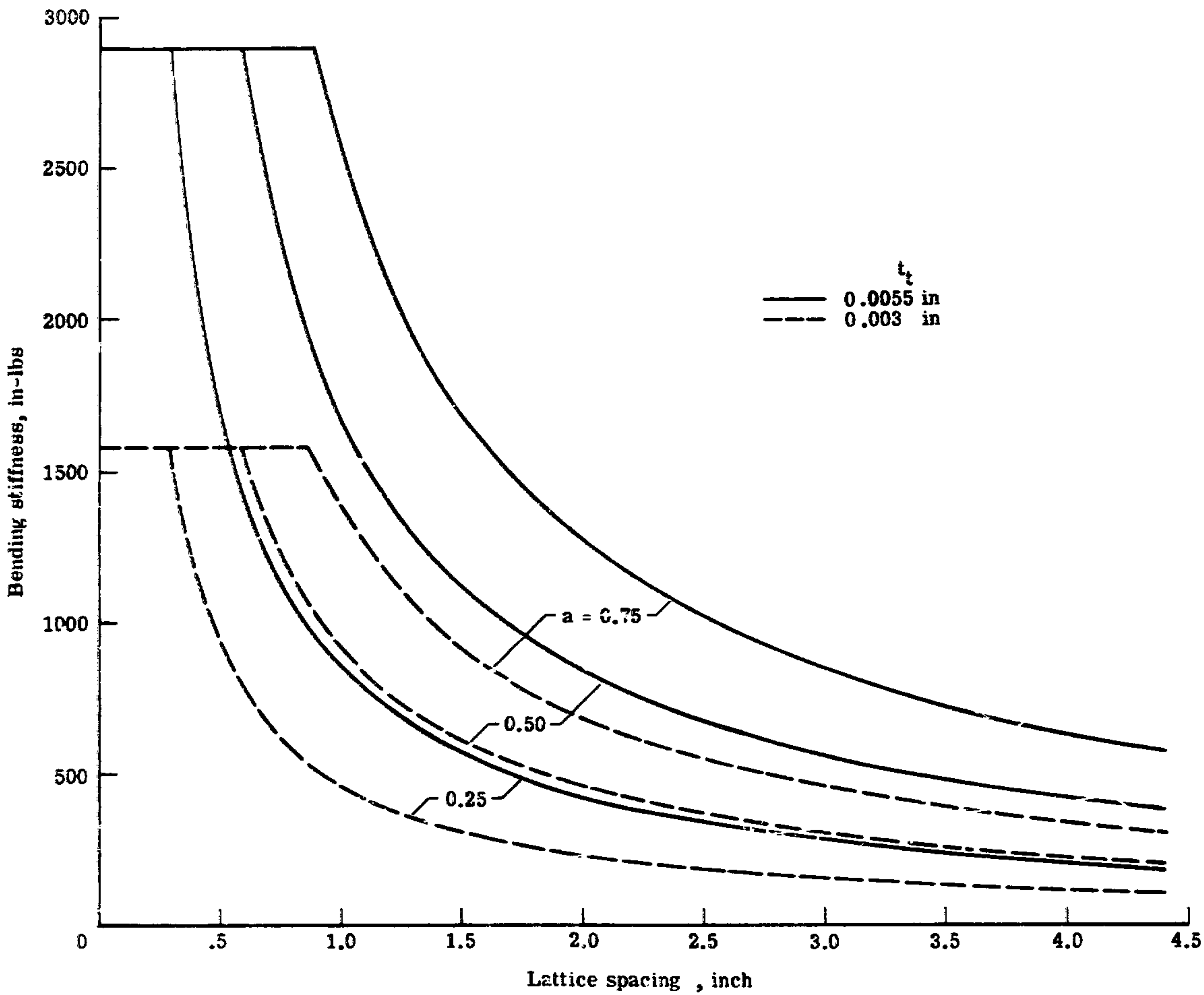


Figure 7.- Plate bending stiffness of lattice panels based on properties of commonly available materials.

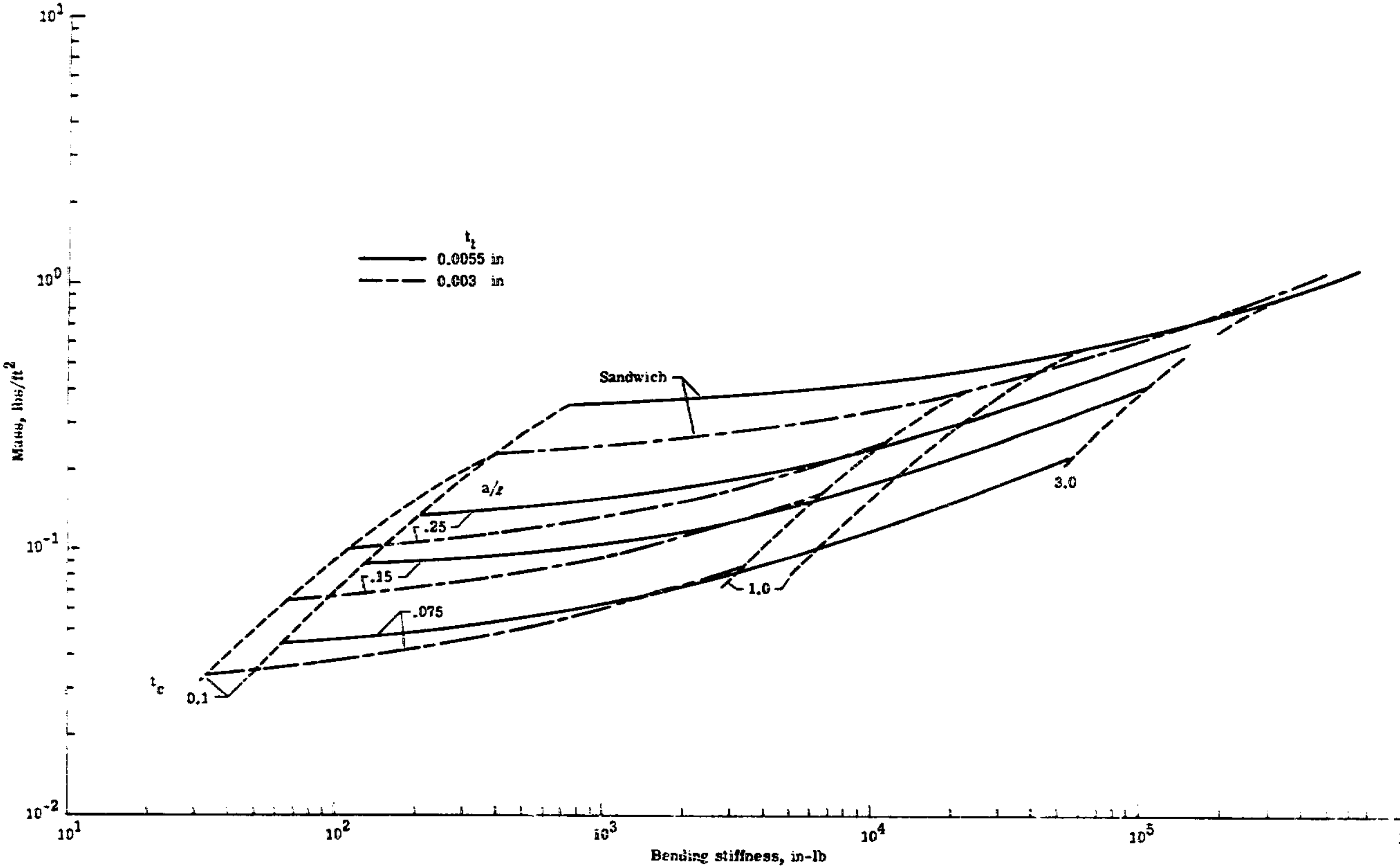


Figure 8.- Carpet plot illustrating typical panel mass as a function of plate bending stiffness for panels fabricated from available materials.

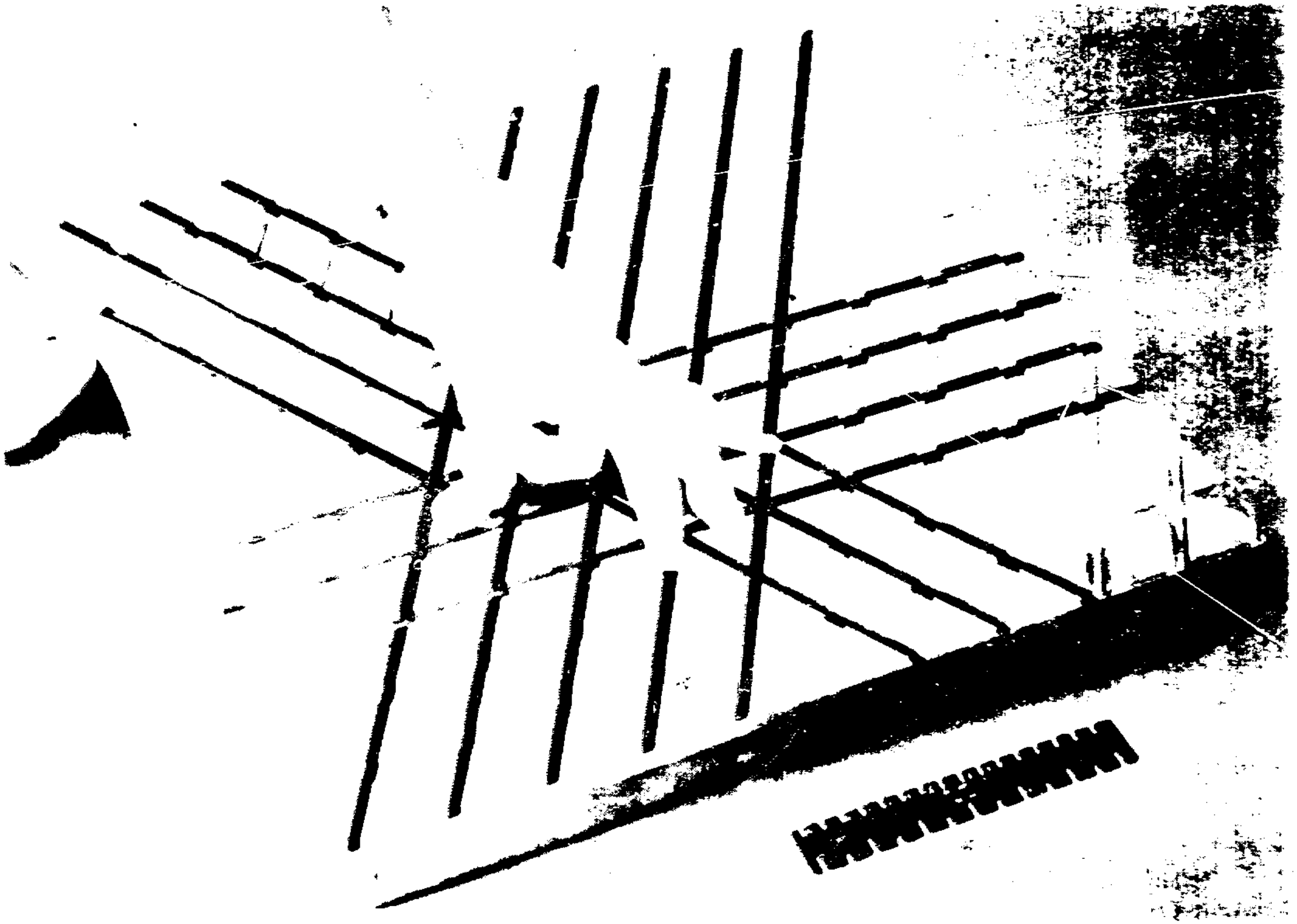


Figure 9.- Photograph showing layup of facesheet in an aluminum mold.

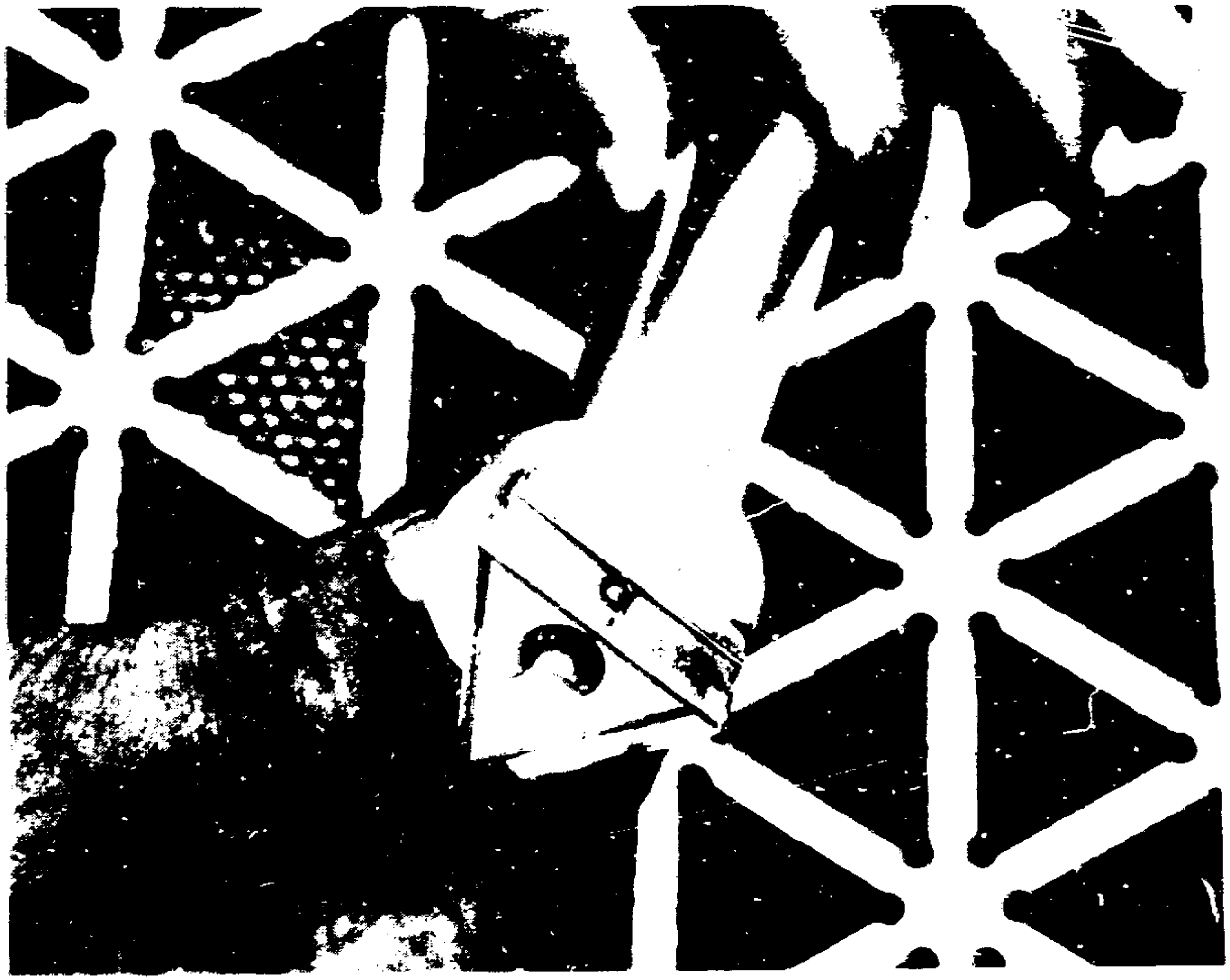


Figure 10.- Photograph of cutter used to remove triangular sections.

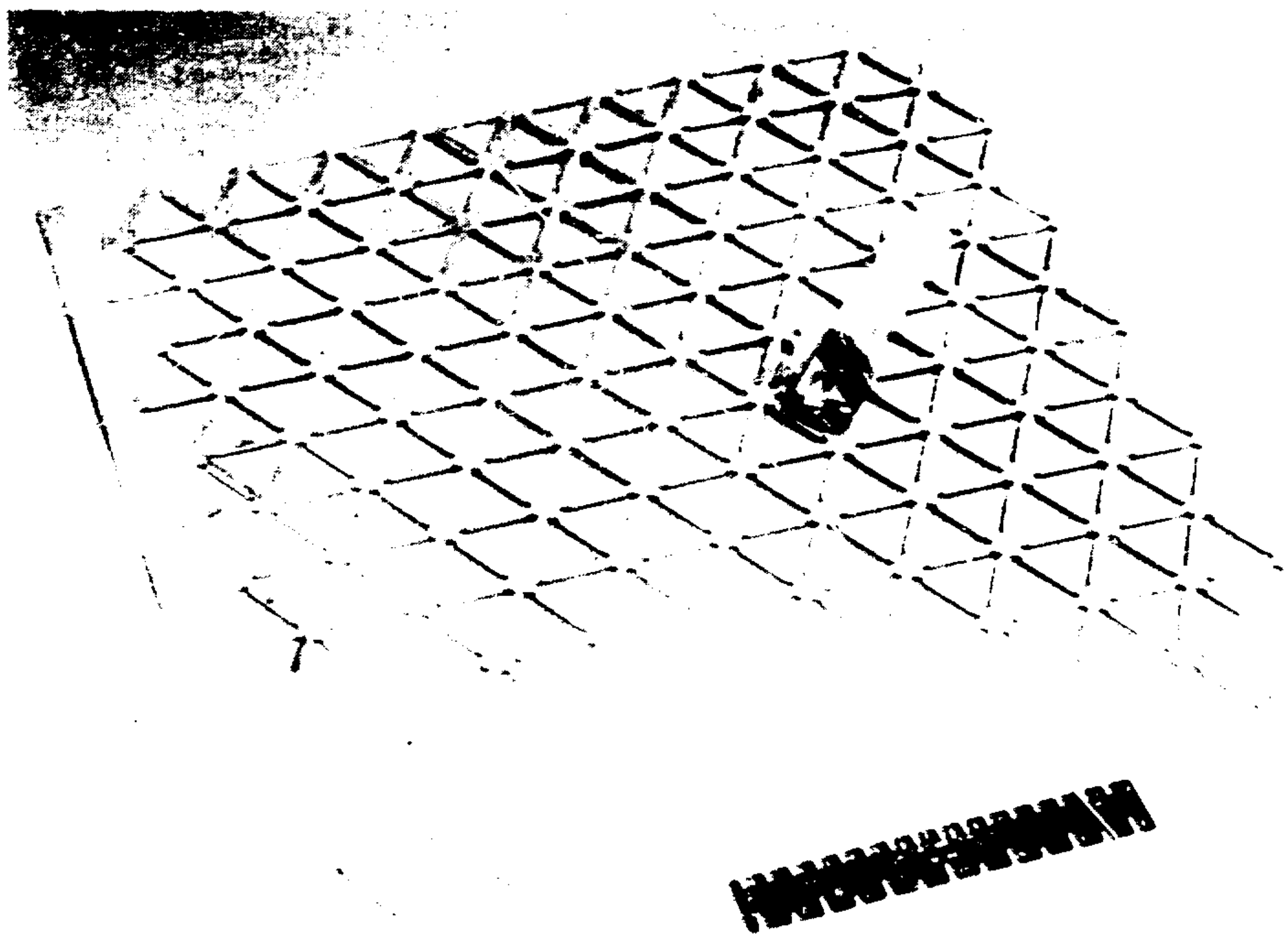


Figure 11.- Photograph of aluminum template used to precut honeycomb core.

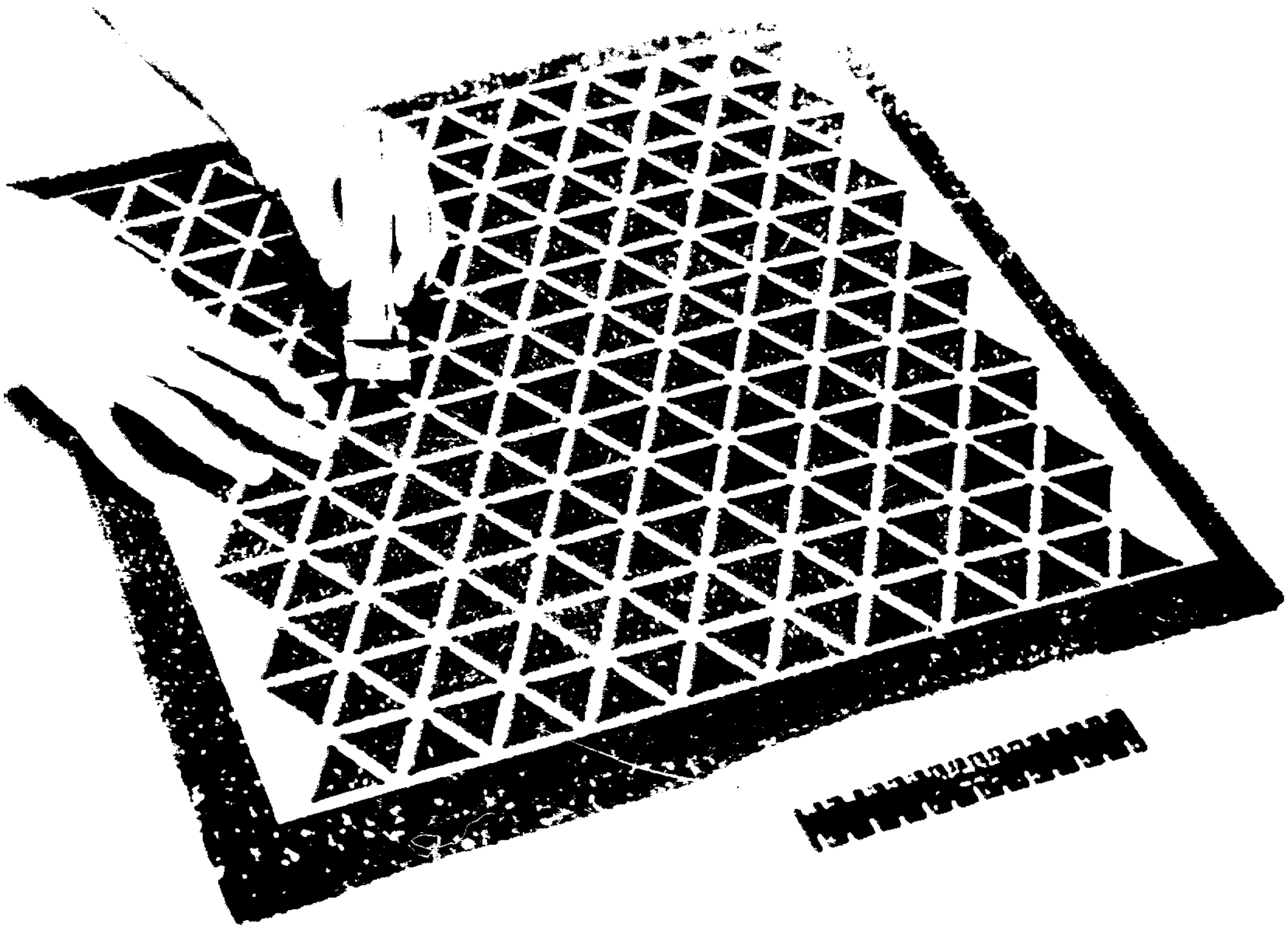


Figure 12.- Photograph showing template and cutter in use.

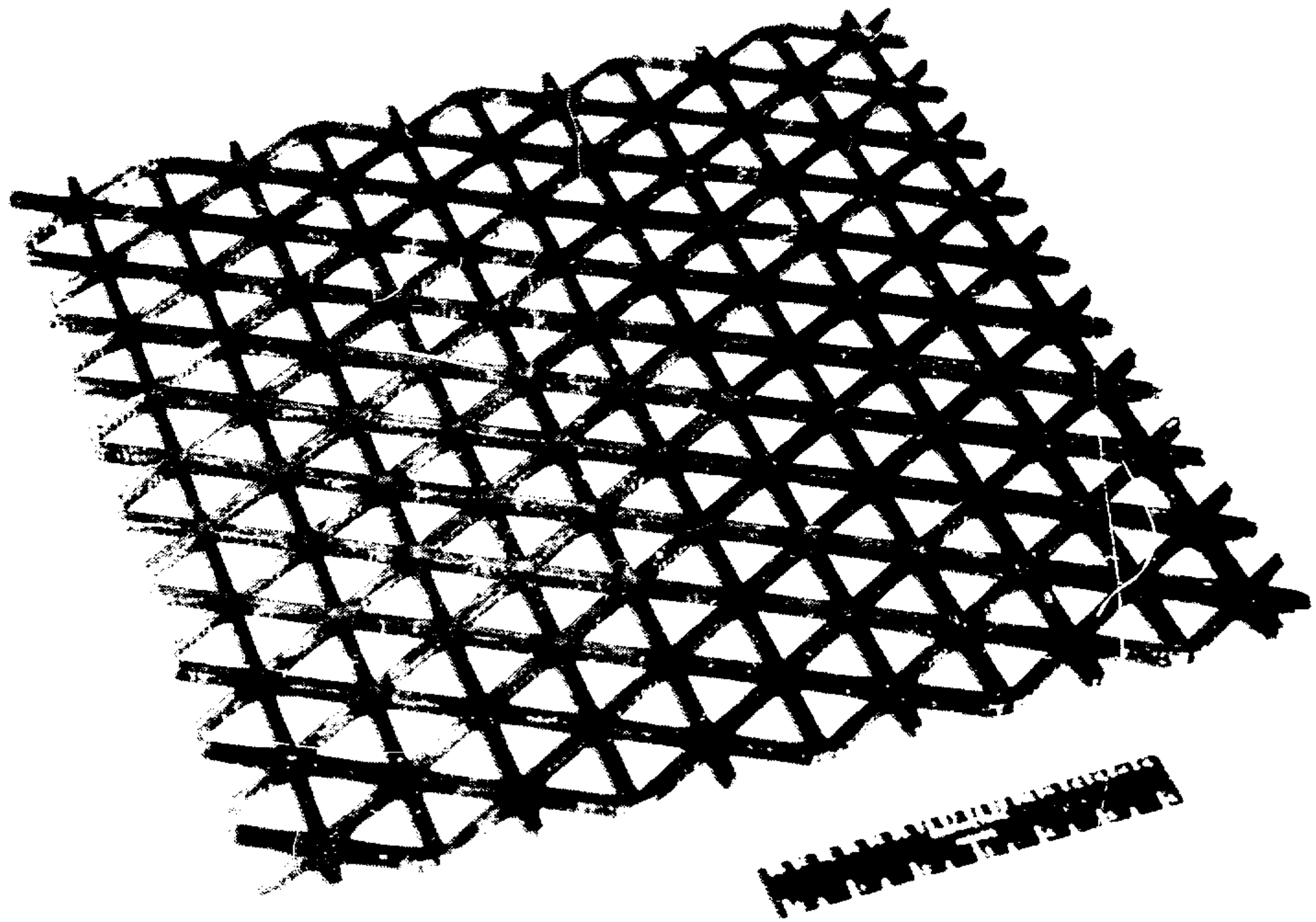


Figure 13.- Photograph showing completed panel.