AN INDUSTRIALIZED HOUSE OF PLASTICS

Thesis submitted in partial fulfillment of the requirements
for the degree of Master in Architecture

Massachusetts Institute of Technology
Cambridge, Massachusetts
24 August 1953

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Albert R. Bodinger

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Lawrence B. Anderson
Head, Department of Architecture

24 August 1953

Pietro Belluschi, Dean
School of Architecture and Planning
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Dean Belluschi:

This thesis, "An Industrialized House of Plastics," is submitted in partial fulfillment of the requirements for the degree, Master in Architecture.

Respectfully,

Albert R. Bodinger

Arch. - Nov 10, 1953

ABSTRACT

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An important part of the architect's role is to explore the possible architectural uses of new materials and methods. Of the new materials today, the plastics in general, and fiberglas reinforced polyester resin in particular, warrant being looked at in this respect. While this has been done to some extent already, most frequently the plastics have been used as direct substitutes for conventional building materials without sufficient regard for their own intrinsic properties. An outstanding distinction of fiberglas reinforced polyester resin (FRP) is its great strength and its ability to be economically formed into relatively large (500 sq. ft.) structurally continuous pieces. In addition, this material has good dimensional stability, excellent weathering properties, corrosion resistance, can be integrally colored, and resists insect and vermin attack. (It is presently produced in a range of products including boats up to 200 ft. long, armor-plate, and washing machine agitators.) In the design of an industrialized house, plastics, especially FRP, show good promise of contributing to a successful result as a consequence of the economy that is possible in their manufacture and ultimate use. The design proposed involves mainly a construction system of structural-skin roof and floor panels and large non-structural wall panels. These components make up a modular bay, and three or more of these bays are combined with considerable flexibility to achieve a highly industrialized house.

FOREWORD

This is a report on the study of a system for house construction employing industrialized methods and plastics materials. So far the study has been a short one, and for this reason as well as others, it has many limitations. Nevertheless, it represents a start which might well serve the purposes of further investigation. Apart from the actual design problem a major job has been to abbreviate something representative and convincing from a large body of information. I would like to thank the following people for their help:

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Mr. Richard W. Hamilton, Research Associate
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Prof. Lawrence B. Anderson, Head
Dept. of Architecture, MIT

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Mr. Frederick J. McGarry
Dept. of Bldg. Engnr'g & Constr., MIT

Mr. Ralph F. Hanson, Head
Marketing Dept., and his associates in the Plastics Division,
Monsanto Chemical Company, Springfield, Mass.

The Architects Collaborative, Cambridge, Mass.

The Graduate Class of 1953, Dept. of Architecture, MIT

Bernicé L. Bodinger, my wife

CONTENTS

1. Purpose of this study

One of the main purposes of this study is to develop some possible architectural applications of plastics.[1] Fiberglas reinforced polyester resin[2] appears most promising for the applications developed in this report, and for reasons discussed later, most attention has been focused on it. Another purpose, perhaps more general but equally important, is to define an example of a new and important role for the architect. It is essential for him to synthesize with new tools and materials and to take a more direct part in their development. In other words, there are people who know the answers, including researchers, product developers, industrial engineers, manufacturers, etc., and they are separated by a large gap from the people who best know the problems, in this case, the architect. This study is an attempt to bridge this gap.

2. Procedure

A letter[3] was sent to twenty-two major organizations in the plastics field. These organizations comprise basic suppliers, molders, and fabricators. A bibliography was compiled, and over a period of four weeks reading and interviews were the main activity. A day's visit at the Monsanto Chemical Company in Springfield more or less culminated the period of preliminary investigation.

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[1] Plastics are organic materials (compounds of carbon with other elements, chiefly hydrogen, oxygen, and nitrogen) capable of flow when the necessary heat and pressure are applied at some stage of their manufacture. For a comprehensive definition see Joseph B. Singer, PLASTICS IN BUILDING (The Architectural Press: London), 1952, pp. 11-13.

[2] Polyester resin is formulated by reacting a polyhydric alcohol such as propylene glycol and a dibasic acid such as maleic anhydride with a monomer such as styrene. Its specific properties are discussed later in this report.

[3] See Appendix.

3. Historical background

Since the middle nineteenth century what we know today as plastics have been steadily developed.[4] Most of the attempts to use plastics in specific building applications have been made in recent years. These applications have been mainly in the decorative and protective uses of melamines, styrenes, and vinyls for interior surfacing, and the acrylics for special types of glazing.[5] During World War II a notable advance was made when the fiberglas reinforced polyester resins were developed, initially to function as radomes, housings for aircraft radar equipment. Since the war this material has found increasing application in various consumer and industrial products ranging from pipes and storage tanks to washing machine agitators and bath tubs. Also, corrugated sheets of fiberglas reinforced polyester resin under various trade names are available. This form of the material is usually advertised to sell largely on its decorative merits for "accessory" architectural uses.

4. Description of problem

In this study emphasis is placed on fiberglas reinforced polyester resin because it seems to offer the best combination of properties for the architectural applications that follow. Most important, its adaptability to low-cost production techniques[6] may well mean that

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[4] The Society of the Plastics Industry, Inc., PLASTICS, THE STORY OF AN INDUSTRY (prepared under the direction of the Public Relations Committee: New York), 1953.

[5] "Formica" is an example of a high-pressure melamine laminate. Styrene is used to produce a ceramic tile substitute, an example being "Church Tiles." Interior and exterior application of a sprayed-on vinyl coating called "Cocoon" is used as a protective and weather seal. "Vinylite" is an example of vinyl used for floor covering. "Plexiglas" is the commercial name of an acrylic that is widely used for dome-shaped skylights.

[6] See Materials & Methods Manual No. 91 in Appendix.

the use of this material could substantially reduce the high capitalization costs that are presently involved in achieving a truly industrialized house. It should be mentioned that we may expect that this particular plastic will be superseded by an even more successful material for a given application. The most optimistic feature of plastics materials in general is that, being so highly synthetic, they have the inherent possibility of perpetual improvement to increasingly satisfy a particular problem. It is a fact that the building industry, especially house construction, lags far behind the market it must satisfy, and that the resolution of this problem lies in the development of the efficiency and economy which is possible only through the use of industrial production and advanced marketing techniques. Also, the decision to design a house rather than, say, a school was made because the scale of the planning problem was relatively smaller, and therefore more time was possible for the consideration of, in this case, more basic problems. In addition, the housing problem is certainly preeminent.

5. Fiberglas reinforced polyester resin (FRP)

A distinction of the plastics materials in general is that they are capable of a high degree of continuity. While it is true to some extent that all materials which can be shaped by one means or another are capable of continuity, few of them can achieve this to so high a degree and with the same facility as the plastics. This is especially true of the low-pressure laminated reinforced polyester resins. Continuity results in a generally more efficient structure and allows for a radical reduction in the number of seams or joints, "the weakest points in all man's constructions....where the chemical and physical attacks of the environment always find their first toe-hold."[7] Previous applications of plastics have made little use of this advantage. By and large the material has been used as a direct substitute for the more conventional materials such as wood, concrete, steel, glass, etc. FRP can combine such properties as resistance to weathering, corrosion, insect and vermin attack, fire, impact, and abrasion. In addition, it can have dimensional stability, light weight, integral color, and extraordinary strength properties. Again, perhaps the greatest advantage of all is that many of these properties can be modified and that the range of modification becomes greater all the time. While this is certainly no magic material and has in fact suffered greatly from much misinformation about it, its potentialities are highly encouraging.

6. General structure

The concept of a separate skeleton and skin is more or less contrary to that of structural continuity. In the stressed skin panel there is a high degree of continuity among the parts of the panel itself; welded steel construction provides an example of the continuous skeleton or frame as does poured-in-place concrete framing. But in these cases the skin or weathering surface is still to a large extent separate from the main structural support or skeleton and is usually not counted on to assume an appreciable structural role. Concrete shell construction provides an example of genuine structural continuity where there may be, in effect, a single and complete structural

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[7] For a discussion of continuity see James Marston Fitch, AMERICAN BUILDING (Houghton Mifflin Company: Boston), 1948, pp. 183-85.

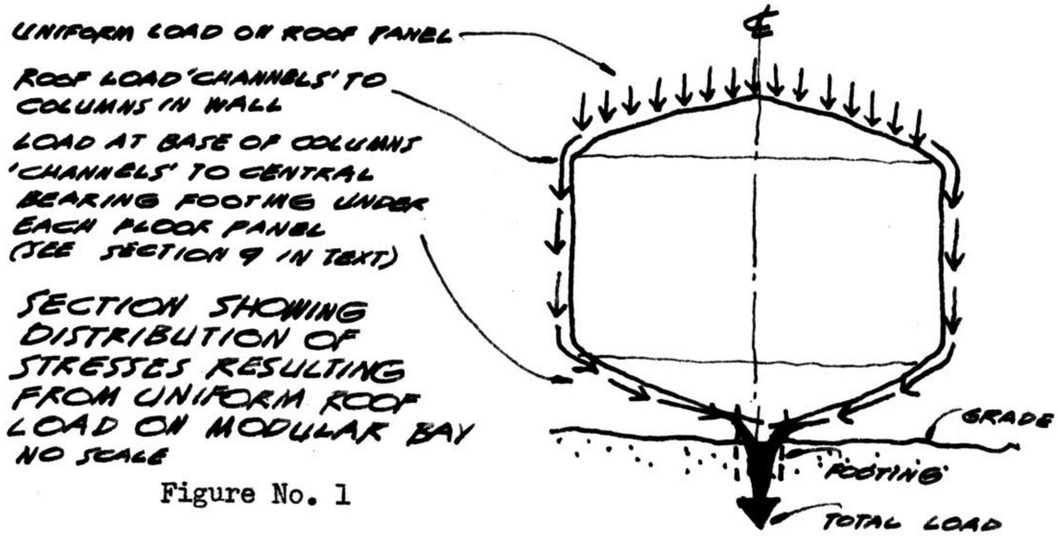
and enclosing unit. This is a good basis for an investigation of the structural possibilities of reinforced plastics, though the plastics of course do have distinct advantages over concrete in general. (The possibility of a completely enclosing plastic dome is not considered primarily because as an architectural solution for a dwelling space, while it may be an inevitable one, it is a longer-range problem than the one being dealt with here. Generally, this study attempts to design houses which represent a progressive step that can be realized now. Reasonably assured marketability is an important objective and does not necessarily imply a bad compromise.)

7. Roof

Generally speaking, structural elements act more or less vertically or horizontally in relation to the ground plane, and those which act vertically can be more efficiently developed than those which act horizontally. Also, in flexure FRP has an E value which is of relatively low magnitude compared to its compressive and tensile strength.[8] For these reasons there is an advantage in minimizing the extent to which the material must act flexurally. Considering a panel of FRP, square in plan, this advantage can be gained in two ways: first, by eliminating perfectly horizontal surfaces, and second, by breaking up the resulting pitched surfaces to achieve an area of each which will not deflect critically. This is accomplished by a system of creasing. Other advantages that result from this handling are increased over-all stiffness and known lines of stress concentration along the creases. The resulting shape is a modified, square-base pyramid (see plate 4).

[8] See Materials & Methods Manual No. 91 in Appendix.

As a roof surface, the greater part of a uniform load acting on this panel is "collected" along the creases. Since all the creases eventually gather at each of the four corners of this surface, a uniform applied load will distribute along the pattern of these creases and be resolved, theoretically, into four equal and concentrated loads, one at each of the four corners. Resultant stresses along the outer edges of the panel are largely eliminated, and this means that there is relatively little beam action (flexural stress) in the panel itself. Used as a roof surface, no beams are required to support the panel. The comparatively inefficient flexural use of the material is considerably reduced.



SECTION SHOWING DISTRIBUTION OF STRESSES RESULTING FROM UNIFORM ROOF LOAD ON MODULAR BAY
NO SCALE

Figure No. 1

Alternatives to this form for the roof include the dome. This is ruled out as a possibility because the load at its outside edge is uniformly distributed. This continuously loaded edge would have to be supported by beam action or some other continuous bearing. A further limitation of the dome is that in order for it to be structurally efficient, its volume becomes disproportionately large. This means that relatively more of the material must be used to cover a given area in plan.

Another alternative is the two-way arched vault where the load is concentrated at specific points on the perimeter of the form, but here are again the disadvantages of excessive material and inefficient enclosure. Also, with such an arched vault there is a rather complicated problem in joining adjacent panels. Actually, the modified pyramid discussed above represents a refinement of the two-way arched vault, maintaining its advantage of load concentration but lessening its disadvantages of volume enclosure and complicated meeting edges between units. As the examples discussed show, only those possibilities that are isotropic, or two-way acting, are considered. This allows wide flexibility in relating panels to each other and results in uniform and bilateral stiffness.

Some added strength at the edges of the proposed "pyramid" panel is necessary because there is a small amount of beam action here, and also because this is where the rigid connections between panels occur. This necessary stiffening is achieved by turning down the edges. By shaping the turned-down part of the panel edge, a through access among the units is provided.

The weathering joint between panels is handled separately from the structural connection and is designed to allow for a certain amount of tolerance within the connection. Possibilities for the outermost weather seal include taping, adhesive-coated panel edges, interlocking gasket, or a brush-on coat of resin. This latter is not favored because it means handling a wet material on the job. Joined together, the panels, or structural skins, integrally colored for heat reflectivity, make up the entire roof. The actual engineering of the panels and joints is not within the scope of this report.

8. Walls

Besides acting as enclosure, the walls incorporate the compression members that are necessary for the transfer of the concentrated roof loads, though the wall panels themselves are non-structural. These compression members also serve to lock the wall sections together. The wall sections themselves are formed so that they interlap (see plate 4). When they are interlapped, there is a through vertical opening at the lapped edges. The compression member is then let through this opening. This operation is similar to mounting a hinge pin. The compression member is completely enclosed in the wall itself, and an efficient lateral tie between wall sections results. A weather seal as discussed above is provided between sections. The actual detail of attaching one wall panel to another allows all joints--whether in-line, right angle, or re-entrant--to be identical (see plate 4). There are no atypical joint conditions. The top of the compression member ties directly into the turned-down corner of the roof panel, and the bottom, into the turned-up corner of the floor panel. This member, a column, is designed taking into account only its compressive strength. Its slenderness ratio is not critical because the encasing wall section restrains it from any sideward bending. Openings in the wall are formed during fabrication and, with one minor exception, involve no cutting and fitting of casing and trim pieces either on the site or during production. The single exception is bonding a lubricant-filled extruded plastic track section around the panel openings. Sliding doors and windows are used. The windows are frameless except at their meeting edges. Between its two surfaces of integrally colored FRP the wall section contains necessary stiffening and insulation of foamed urea-formaldehyde.

9. Floor

The floor is made up of the same basic unit as that used for the roof. Where in the roof this unit bears on its four outer corners or points, in the floor it is inverted and bears on its apex. In other words, the distributed roof and floor loads are channeled down to a single support under each bay (Figure No. 1). In the floor panel the stresses follow the same system of creases as in the roof but in the reverse direction. The concavity of the up-turned pyramid is infilled with a collapsible cellular grid. The bottom of this grid conforms to the shape of the floor unit and is mechanically bonded in place. On its level top is installed the finished floor of FRP which acts structurally to the extent of spanning the spaces between grid cell walls. This distance is in terms of inches. Also, the cell walls are sufficiently perforated to allow the floor cavity of each modular unit to function as a plenum chamber. Insulation is included.

10. Footings

A minimum house comprises three modules. Since each module or bay 'bears at the ground on one support, this house is stable with the minimum number of footings. The footings themselves are of pre-cast concrete and hollow. Each one may house a unit heater. A receiver cap of FRP is anchor-bolted to each footing. This cap is molded to the shape of a segment of the floor panel to which it connects.

11. Mechanical system

For heating, the hollow floor structure acts as a plenum chember and is augmented by registers in the finished floor or walls. This combines the advantages of a hot air and a radiant heating system. If it is feasible, an individual unit heater is housed in each footing. This eliminates duct work as such. Heat loss is minimized, and otherwise useable space is not occupied by heating equipment. Zoned control is simple and effective. Fuel is fed to each unit heater from an outside storage tank or service supply. Fire hazard is minimized without any special preventive measures. Each modular unit has in effect its own heating system, and this contributes to the over-all flexibility of planning possibilities. A drawback to this idea is that each unit heater would require a rating of approximately 15,000 BTU/hr output. This is uneconomically small and results in an inefficient burning unit. Initial proportionate cost of such a unit is high. Also, no unit of the required size is presently available which is capable of burning #2 grade oil, cost-wise the most satisfactory for domestic heating. On the other hand, this idea has not really been investigated conclusively enough to outweigh the advantages mentioned above.

The plumbing system employs FRP, butyrate or vinyl piping for cold water supply and waste lines. Hot water supply may require copper. The flexibility of plastic pipe and the ease with which connections may be made greatly relieve the problem that conventional rigid piping entails with its complicated installation when any kind of flexibility is required. Economical plumbing is not a plan-limiting factor when using plastic pipe. The electrical wiring system is concealed and completely flexible in the access space between the finished ceiling and the roof panel. Exterior walls and interior partitions with pre-installed switches and outlets are wired to plug into this overhead feed.

12. Interior fittings

The following items are furnished with the house. Storage units of FRP are one-piece molded to a standard dimension. They function as interior walls frequently, and for this reason they incorporate sliding-door tracks to receive room-to-room sliding doors when the plan calls for this. Since some plans may require an interior column, these storage units incorporate the necessary compressive strength at a corner so that they can function as columns when necessary. Finished ceiling panels are of plastic-treated paper in various colors. These panels are translucent so that concealed lighting in the above ceiling access space can come through. These ceiling sheets are creased in various ways for stiffness. They either snap into a track which runs around the inside perimeter of each roof panel, or they are hung from a supporting grid made up of extruded plastic channel sections which snap into this same track. The finished ceiling can have many forms and is frequently concave upwards. The supporting grid is adjustable and also functions as a curtain track. When roof insulation is omitted, the roof panel becomes a translucent skylight. Soundproof interior partitions are made of two sections of molded FRP that fit together in box and lid fashion. These partitions are hollow in section and are filled with sand after being installed. A tight floor seal is gotten by the use of a neoprene or vinyl gasket which is held in place against the finished floor by suction or an adhesive. The head of the partition fits into a channel of the ceiling grid. The finished ceiling butts this channel and may be taped at this joint or received in a prepared groove. Placing the partitions involves no cutting, and they may be located and relocated without the use of tools. All doors are sliding.

13. Economy

The reduction of site labor is the key to the economy of an industrialized house. Repeatedly, entrepreneurs in the field have failed either for not recognizing or for not sufficiently satisfying this first principle. Often, though industrialized methods have been employed in the factory, this has not adequately reduced on-site operations. It is this idea of reducing site labor that is an over-all criterion in this study. A rough index to the extent of site labor is the amount of cutting and fitting that take place on the job. In the system of construction described in this report, this practice is virtually eliminated because of the dimensional stability of the materials involved, a design of the joints which allows for any necessary tolerances, and the fact that most of the relatively smaller pieces involved in the entire house are pre-assembled. The elimination of handling wet materials on the job, the assurance of pieces arriving in proper condition after transporting, a radical reduction in the actual number of parts involved at every stage, and the minimizing of excavation also reduce on-site operations. The site itself may be left substantially undisturbed except for the preparation of footing holes, and even these are held to a minimum. Today a major on-site activity, typical of even the most successful industrialized house installations to date, is final finishing such as painting, papering, glazing; mechanical installation and weather sealing. These practices are greatly reduced or eliminated in the industrialized house of plastics. Another rough index of cost other than site labor is the number of pieces and, related to this, the number of processes a given item involves in being produced. By this standard as well, the industrialized plastics house embodies an overwhelming advantage generally.

While there is nothing new in principle about the mechanical installation proposed here, it benefits generally from the other advantages involved in the over-all design and so represents an improvement over current practice.

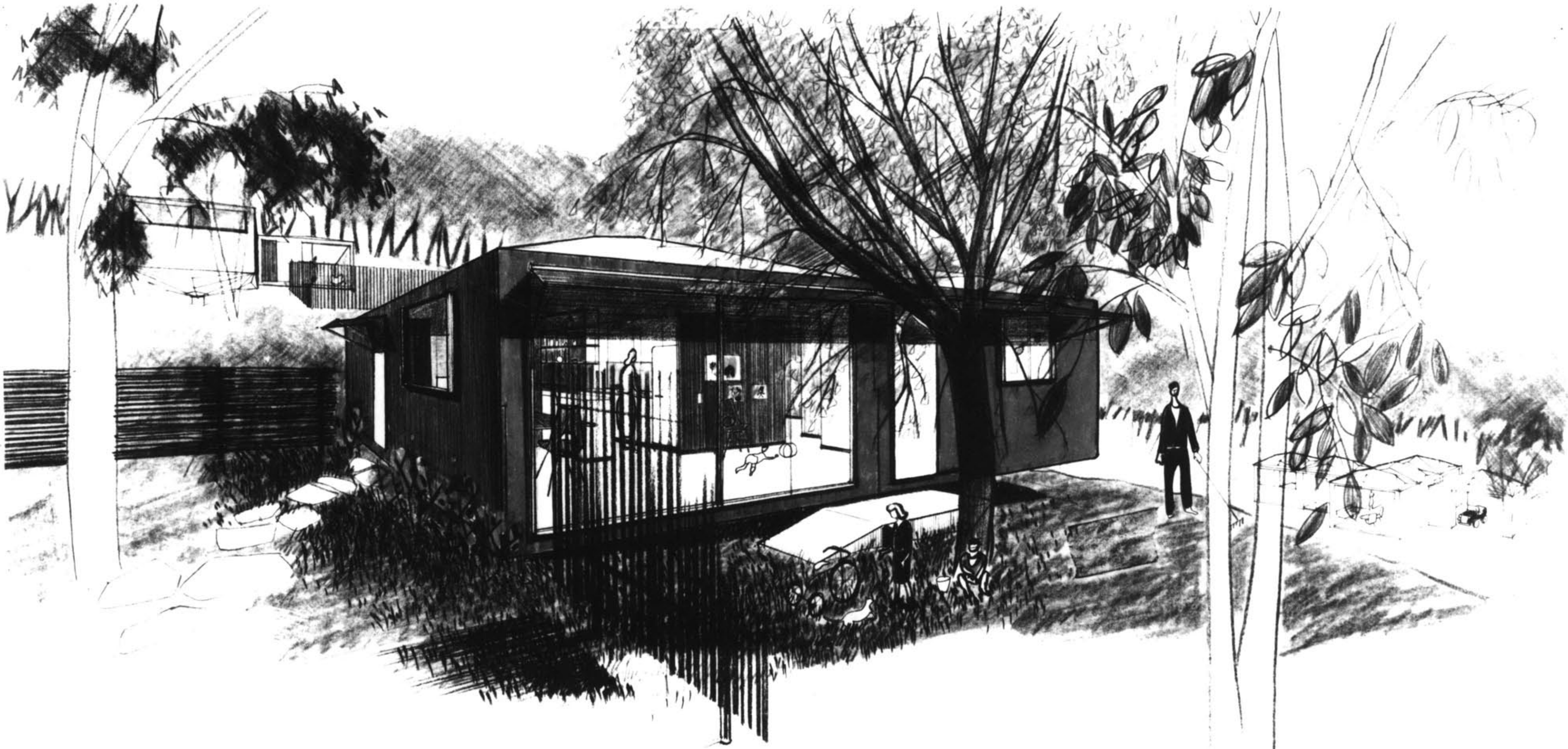
It is repeatedly pointed out that the basic materials cost of plastics in general, and FRP in particular, is far greater than conventional materials. But these costs do not afford the basis for a realistic comparison. For if the **initial** materials cost of plastics is greater, all the further expenses including fabrication, assembly, shipping damage, maintenance, and replacement that contribute even more to the final selling price of the product may be far less in a plastics house.

14. Size of modular unit

A 16-foot square in plan was arrived at for the following reasons: the number of joints in order to be reduced should come as infrequently as possible. At the same time, the over-all size of a piece is limited by problems of fabricating, handling, storage, and transportation. A 16-foot sq. roof or floor panel of FRP weighs about 600 lbs., and a 16-foot-long by 8-foot-high wall panel weighs a maximum of about 500 lbs. Also, for shipping and storage, the roof and floor panels will nest in a volume 7½'x 16'x 16' for a thousand-foot house. Neither this weight nor this volume is excessive according to local truckers. Architecturally, a minimum space of 16' x 16' is an excellent average standard for any of the basic areas in a house judged according to the relatively high criteria established by the American Public Health Association. A 16-foot square on the basis of plan studies made so far is a good dimension within which to achieve flexibility of sub-division into smaller spaces such as bedrooms, play space, study, kitchen, bath, etc. It is a multiple of the currently accepted 4-inch, 4-foot module as well. This means that any of the parts reported here could be incorporated into an otherwise conventional structure. While this use is not within the scope of this study, it is an important application of some of the ideas presented here. Exact sizes as such are tentative and could be altered for any good reason without contradicting any of the basic arguments already presented. In other words, any size that is a good compromise between using the qualities of the materials to advantage and applying them well in an architectural sense would be a good size. As an example, the weight of these panels may be prohibitive, or perhaps the present module dimensions are too large for architectural reasons.

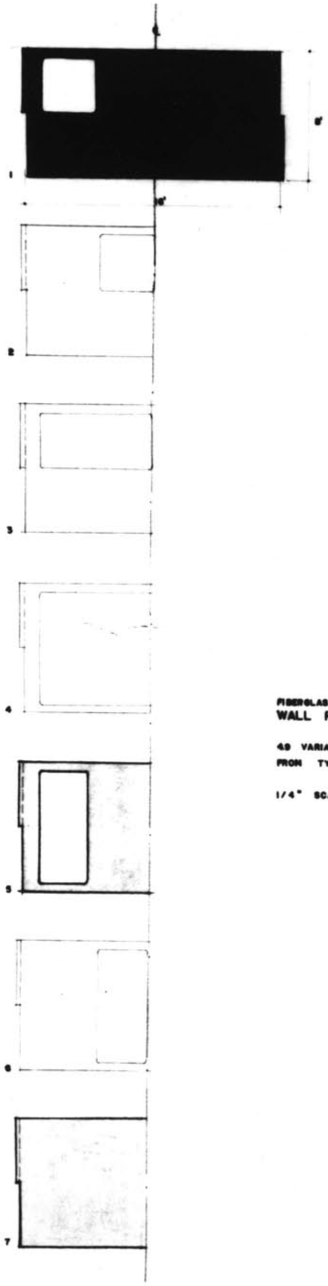
15. Flexibility

The design of the joints allows the entire house or parts of it to be dismantled and reinstalled without the alteration of any of the materials. It may be readily added to or subtracted from. Exterior walls can be switched around. The design of the roof, wall, and floor sections permit a wide range of architectural solutions, all based on the same basic building unit. The range of plan designs that are possible also means wide adaptability to a variety of site conditions. This adaptability is further increased because of relatively few points of bearing at the ground. Parts of or the entire structure may be elevated or depressed with a minimum of site alterations.



an industrialized house of plastics

BODINGER AUGUST '53

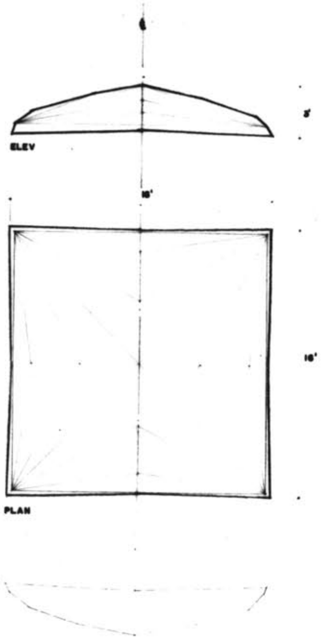


FIBERGLAS REINFORCED POLYESTER

WALL PANEL TYPES

49 VARIATIONS POSSIBLE
FROM TYPES SHOWN

1/4" SCALE



FLOOR SIMILAR & INVERTED

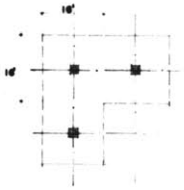
FIBERGLAS REINFORCED POLYESTER

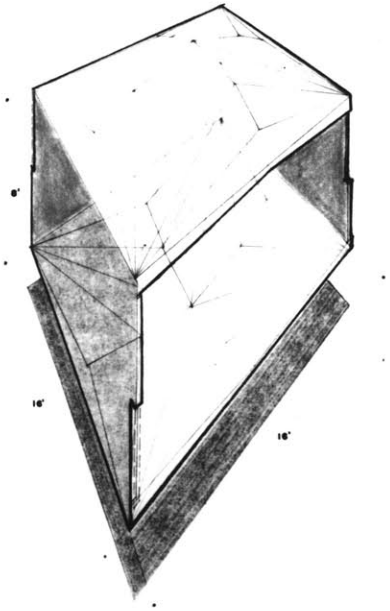
ROOF & FLOOR PANEL

PANEL IS CREASED AS SHOWN: 1. FOR STIFFNESS 2. TO MINIMIZE FLEXURE 3. AT ROOF TO RESOLVE UNIFORM LOAD INTO 4 EQUAL LOADS AT CORNERS 4. AT FLOOR TO RESOLVE CONCENTRATED LOADS FROM CORNERS INTO SINGLE CONCENTRATED LOAD AT CENTER OF PANEL

PANELS NEST FOR STORAGE & SHIPPING

FOOTING DIAGRAM
MINIMUM HOUSE OF 3 BAYS





MODULAR BAY

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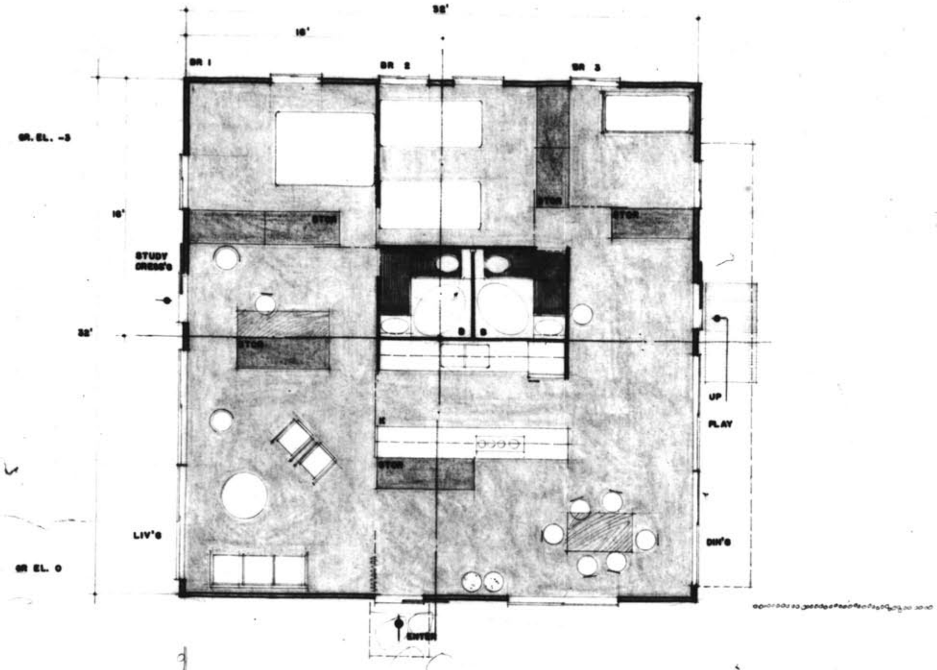
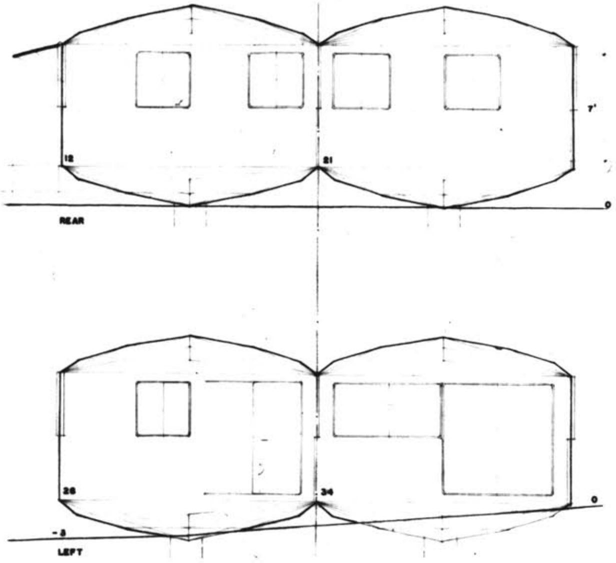
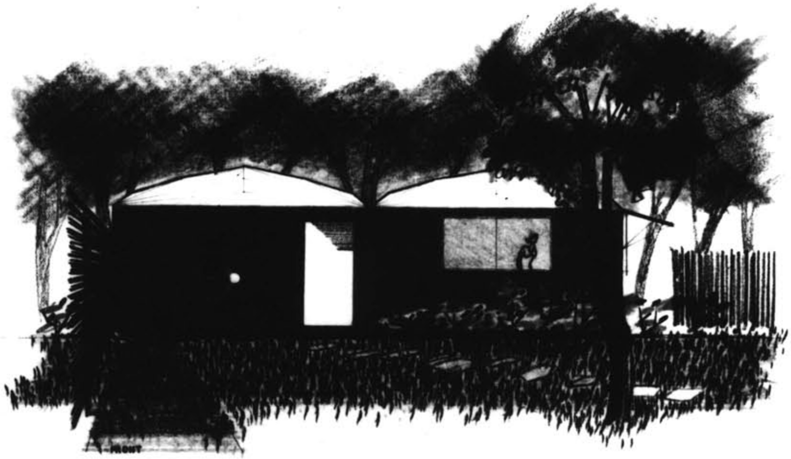
p

2 BODINGER AUGUST '53







1/4" SCALE

4 MODULAR BAYS AT 256 SQ. FT. = 1024 SQ. FT.
3 BED ROOM MODEL

ALL DOORS & WINDOWS ARE SLIDING
ALL STORAGE UNITS ARE MOVABLE

3 BODINGER AUGUST '53

i
h
p

● FIBERGLAS REINFORCED POLYESTER RESIN

TYPICAL INTERIOR PARTITION

1/2" = 1'-0"

HUNG CIELING

CHANNEL RECEIVES PART'N & SLIDING DOOR

2-PC MOLDED FRP ●, HOLLOW-CORE

FILL WITH SAND ON JOB TO SOUNDPROOF

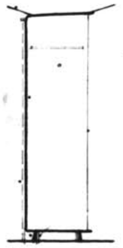
SLIDING DOOR

ADHESIVE SHOE

APPLIED COVE BASE

TYPICAL STORAGE UNIT

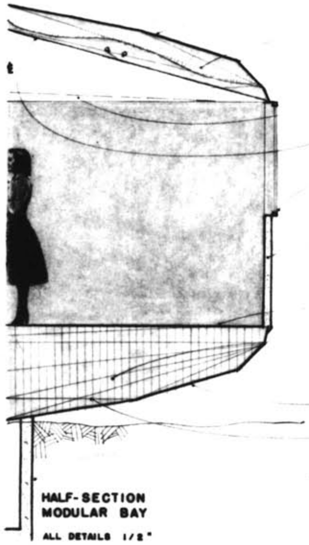
(ACTS AS COMPRESS'N MEMBER WHEN PLAN REQUIRES)



1-PC MOLDED FRP ●

CURTAIN

LEVELING SPACERS



HALF-SECTION MODULAR BAY

ALL DETAILS 1/2"

ROOF PANEL - 1-PC MOLDED FRP ●

HUNG INSULATION

LIGHTING

ACCESS OP'N'S BETWEEN PANELS

HUNG CIELING - CREASED PLASTIC-TREATED PAPER

SLIDING WINDOW TRACK - EXTRUDED PLASTIC (EXTERIOR DOORS SIMILAR)

WALL PANEL - 2-PC MOLDED FRP ● - INSULATION BETWEEN - FOAMED UREA-FORMALDAHYDE

FINISH FLOOR - FRP SHEET ●

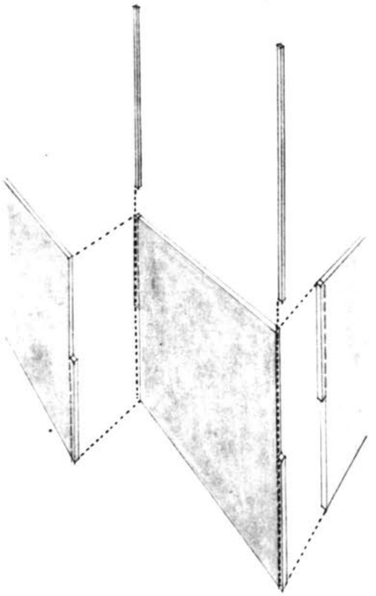
HONEYCOMB COMPRESSION IN-FILLING. PERFORATE CELL WALLS FOR SPACE TO ACT AS PLENUM

FLOOR PANEL (LIKE ROOF) W/INSUL.

RECEIVER CAP - 1-PC MOLDED FRP ● - BOLTS TO FOOTING & FL. PANEL

HOLLOW PRE-CAST CONCRETE FOOT'G HOUSES UNIT HEATER

ALL PARTS INTEGRALLY COLORED



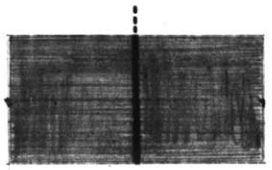
WALL PANELS - COLUMN ASSEMBLY

COLUMNS ACT AS COMPRESSION MEMBERS & ALSO TIE WALL PANELS TOGETHER

WEATHER SEAL BETWEEN PANELS OF 1. TAPE OR 2. ADHESIVE OR 3. GASKET OR 4. RESIN BRUSH-ON OR COMBINATION

ALL JOINTS - EXTERIOR CORNERS, RE-ENTRANT CORNERS & IN-LINE ARE THE SAME DETAIL

CONTINUITY ELIMINATES NEED FOR OTHER WIND-BRACING



ELEV'N

4 BODINGER AUGUST '53

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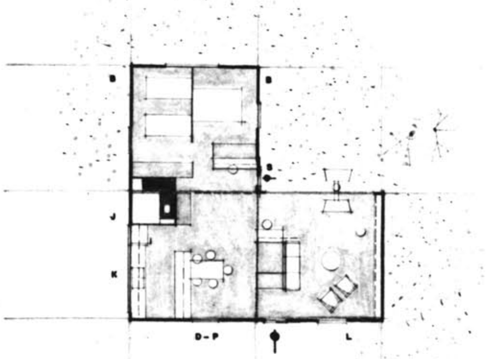
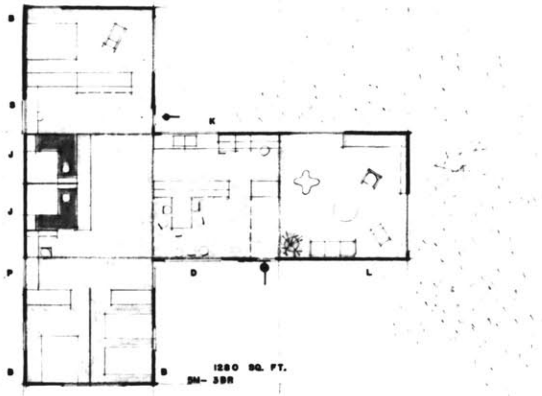


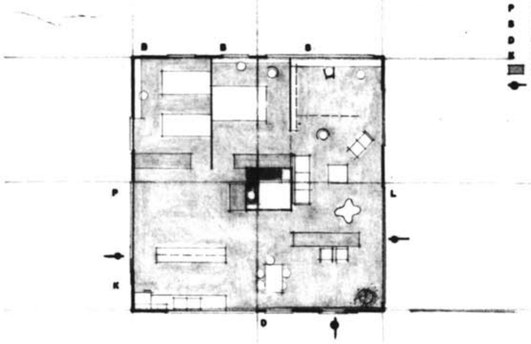
3M- 2BR
768 SQ. FT.
MINIMUM UNIT



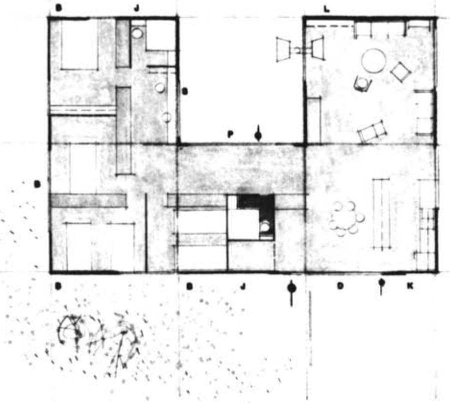
1280 SQ. FT.
5M- 3BR

TYPICAL PLANS 1/8" SCALE

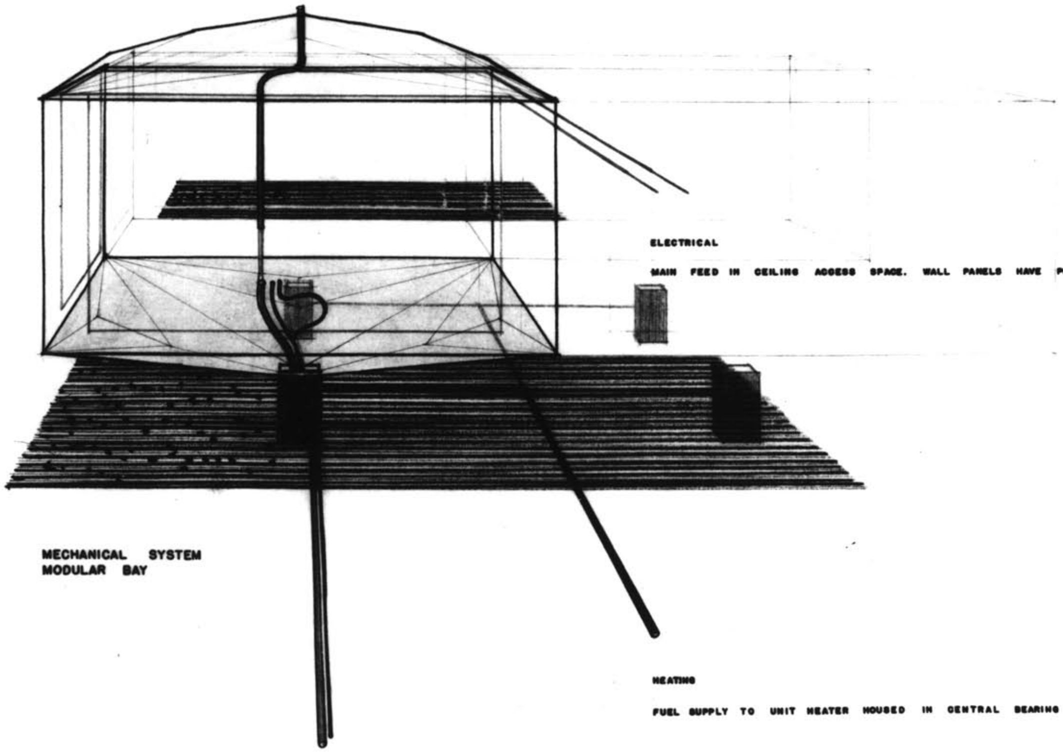
L	LIVING
B	BEDROOM
J	TOILET
P	PLAY-WORK
S	STUDY- DRESSING
D	DINING
K	KITCHEN
▨	STORAGE
●—	ENTER



4M- 2BR
1024 SQ. FT.



5M- 4BR
1280 SQ. FT.



MECHANICAL SYSTEM
MODULAR BAY

ELECTRICAL

MAIN FEED IN CEILING ACCESS SPACE. WALL PANELS HAVE PRE-INSTALLED SWITCHES & OUTLETS & PLUG INTO THIS OVERHEAD FEED

HEATING

FUEL SUPPLY TO UNIT HEATER HOUSED IN CENTRAL BEARING FOOTING AT EACH BAY. FLOOR PANEL ACTS AS PLENUM. REGISTERS ALSO PROVIDED

PLUMBING

NON-RIGID PLASTIC PIPE & FITTINGS (EXCEPT HOT WATER SUPPLY) & NO INTERFERENCE FROM STRUCTURE ALLOW WIDE FLEXIBILITY

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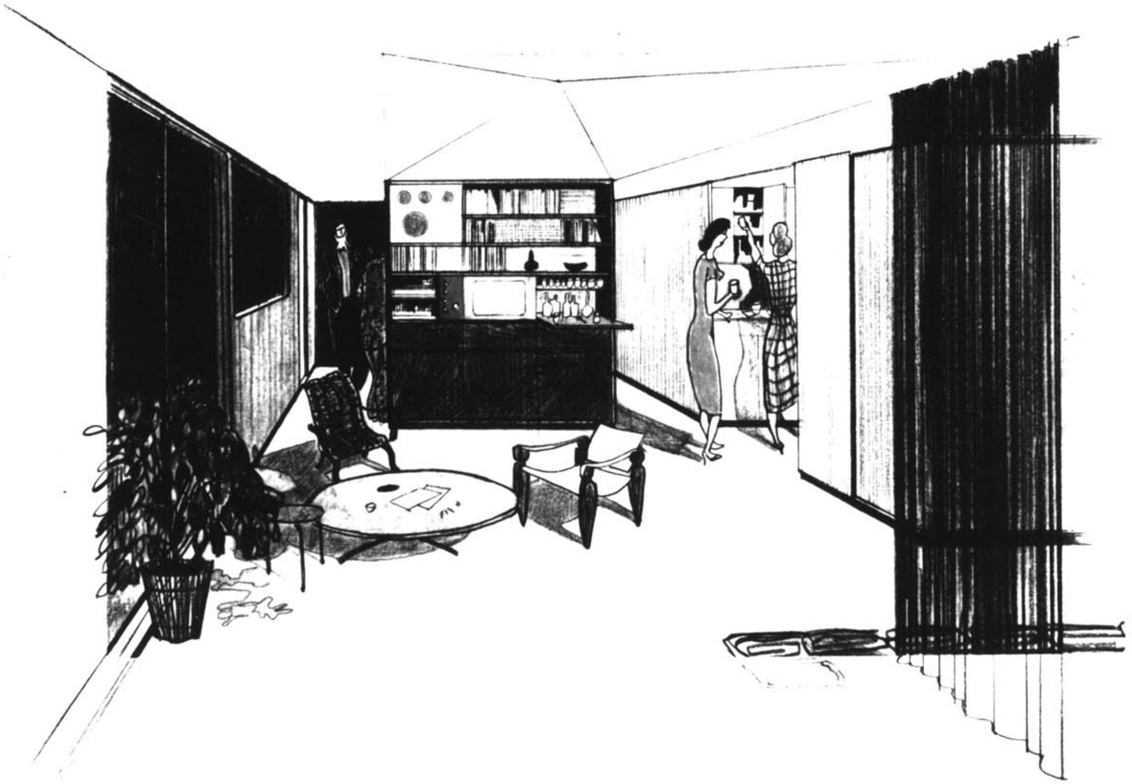
6 BODINGER AUGUST '53 p



LIVING ROOM 4 BAY 3 BR UNIT

APPENDIX A

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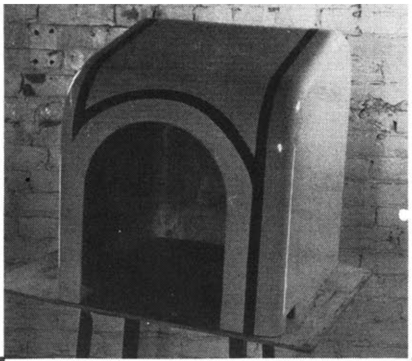
APPENDIX B

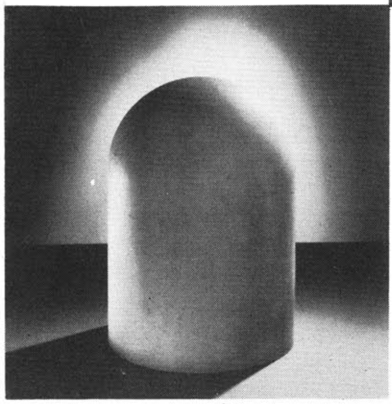
Materials & Methods Manual No. 91 (following)

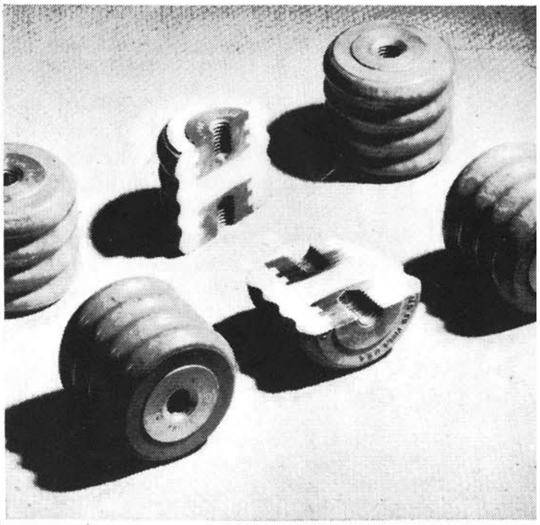
More than forty articles in periodicals, mostly trade publications, were studied. In the plastics field, and especially in the case of fiberglas reinforced polyester resin, there is such rapid development that even information which is of a relatively recent date may be obsolete. For this reason, and to minimize bulk, the reprint included in this appendix was selected as a representative summary of the most up-to-date information on the subject.

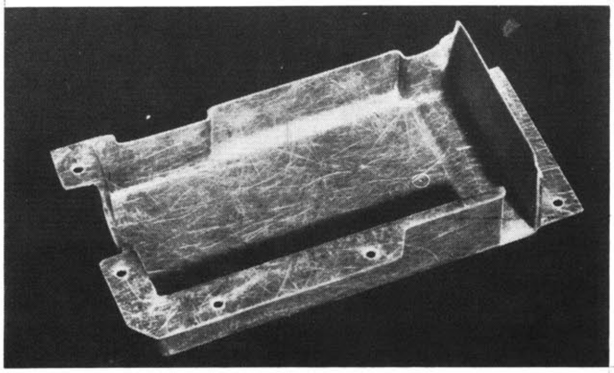
An excellent source of information is the Reference Data File on Fiberglas Plastics Reinforcement, of the Owens-Corning Fiberglas Corporation (available through the courtesy of Mr. J. C. Clement, Jr., Boston Branch). This is especially good because the file is constantly revised and provides, more or less, a running account of developments in the field.

Also, up-to-date technical data is usually available from the organizations listed in Appendix C.









Glass-Reinforced Plastics

by Philip O'Keefe, Associate Editor, Materials & Methods

MATERIALS & METHODS

MANUAL No. 91

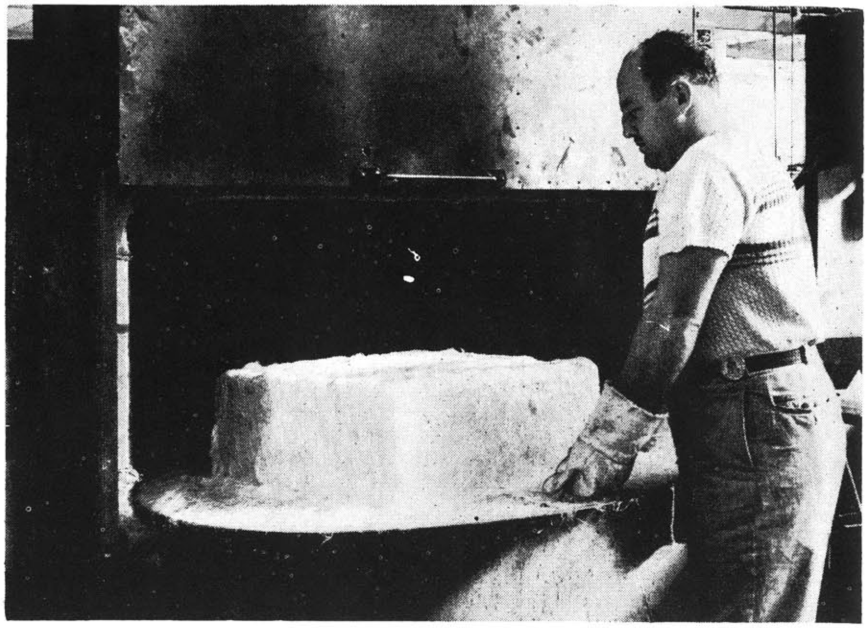
This is another in a series of comprehensive articles on engineering materials and their processing. Each is complete in itself. These special sections provide the reader with useful data on characteristics of materials or fabricated parts and on their processing and applications.

FEBRUARY 1953

The reinforced plastics discussed here are the low-pressure laminates—mainly glass-reinforced polyesters—used in radomes, boats, automobile bodies, metal forming dies, aircraft ducts and electrical apparatus. These materials are new, well glamorized and much misunderstood. In spite of metal-like strength properties, they are not substitutes for metals. Reinforced plastics are finding their own uses. This Manual gives the prospective user information he needs on:

- **Resins and Reinforcements**
- **Molding Techniques**
- **Properties**
- **Part Design**
- **Applications**

Reprinted from MATERIALS & METHODS, *February 1953 issue*
Reinhold Publishing Corporation
330 West 42nd Street, New York 36, N. Y.



Preform for junction box on B-47 jet bomber is removed from wire mesh. (Boeing Airplane Co.)

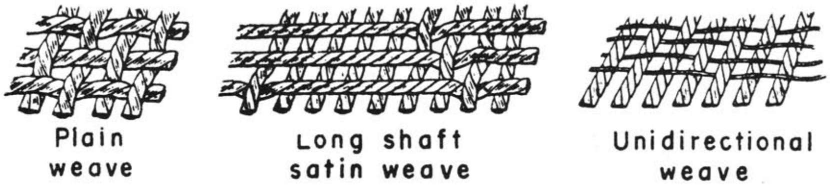
Since 1944, reinforced plastics, especially glass-reinforced polyesters, have been widely publicized. Glass-plastic car bodies recently made news, as did the use in Korea of body armor of the same material. Some reports about reinforced plastics have been fanciful and tend to glamorize the material. There are, however, many substantial applications now in production or under development.

An authoritative definition of *reinforced plastics* is hard to find. In a broad sense, the term covers any mixture of a plastic and fibrous material. Fibers give strength, while the plastic makes the material moldable and stiffens the fibers in the finished material. A rough analogy is reinforced concrete—concrete contributes to compressive strength, stiffness and body, and steel bars take tensile loads.

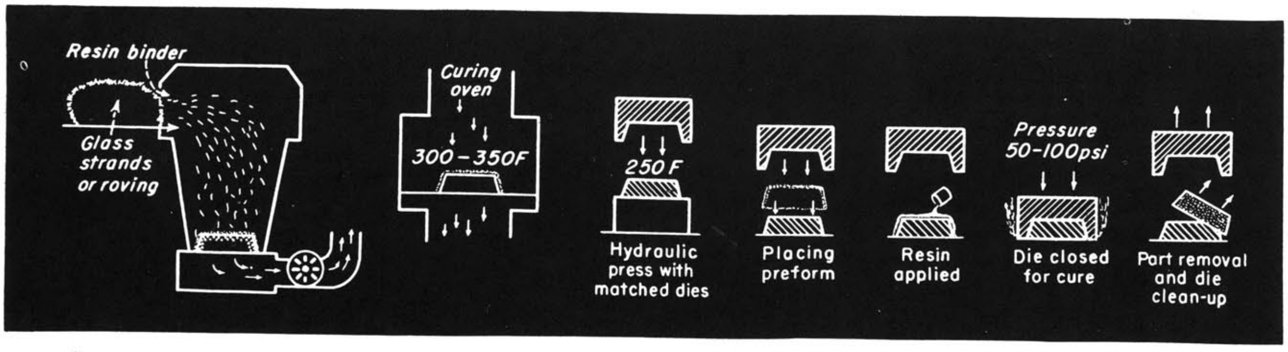
There are many types of reinforced plastics using glass, cotton, rayon, nylon, asbestoes and paper as reinforcing materials. Reinforcements may be cloth or merely random fibers. Thermosetting phenolic, melamine, silicone, epoxy and polyester resins are used. Most widely used are phenolics and melamines, press molded at relatively high pressures into the so-called high pressure laminates. Another type is molded under low pressures (defined here as 300 psi or less) or no pressure at all. Low pressure laminates are mainly polyesters, although silicone, phenolic and epoxy plastics have been used. Although paper, cotton and other materials have been tried, glass fiber and fabric are the usual reinforcements in low-pressure laminates.

This Manual will be confined to the low-pressure laminates. While the dividing line is drawn on molding pressures, the important criterion is applications. In the rest of this Manual the words "reinforced plastics" should be understood to mean only the low-pressure laminates.

These reinforced plastics are new engineering forms as well as new materials. Their value lies not only in properties of the materials, but also in fabrication methods used and part sizes and shapes made. Some polyesters, for example, can be poured into molds or applied to glass cloth or mat and cured with no pressure. No solvent is required to put the resins in liquid form; no volatile constituents are driven off in curing. Thus, no pressure is required. Also, no great strength is required in molds, and part sizes are not limited by press capacity. Large boat hulls molded in reinforced polyesters could



Cloths are classified by weave. Satin fabrics give stronger laminates than plain weave. Unidirectional fabrics give maximum strength in one direction. (Owens-Corning Fiberglas Corp.)



Utility box is made with preform reinforcement. In this typical case, preform binder is cured in 40 sec, and the resin-glass part itself cures in 120 sec. (Owens-Corning Fiberglas Corp.)

not be made in one piece with any plastics which required press curing. Reinforced plastics are not cheap. Sound uses are determined by balancing cost against the valuable combination of properties the materials have. Outstanding properties are:

1. Strength. Tensile strength to weight ratio is claimed to be greater than with any other structural material.
2. Electrical Characteristics. They are nonmagnetic and electrical insulators, and do not stop radar waves.
3. Corrosion Resistance. They are not attacked by sea water, weathering, mild acids, mild bases, many common solvents and many corrosive chemicals.
4. Colorability. Color can be molded directly into the material.

Large parts, like auto bodies and boats, are built up by hand laying cloth and mat and impregnating with resin. (United States Rubber Co.)

5. Nonstrategic. Nothing used in making them is strategic.
6. Resiliency. Medium impact does not produce dents or damage.
7. Dimensional Stability. Humidity and temperature changes from –60 to 250 F have no lasting effects.
8. Thermal Insulation. Heat transmission rate is low.
9. Metal Inserts. Metal parts can be molded in directly.
10. Cheap Moldability. Large, reasonably complex parts are molded in one piece with equipment that is extremely inexpensive compared to the dies and equipment needed for similar metal parts.

On the other hand, there are also limitations. Low-pressure reinforced plastics are not wonder replacements for metals. Neither are they the easy road to get rich quick making parts without proper equipment and experience. Rather than replace metals, they will open up new specialty markets, at least in the foreseeable future. Relatively low-priced custom-made automobile bodies and machine housings are examples.

In general, to be suitable for these materials, a part must require at least two of the ten properties listed above. If strength, corrosion resistance or good electrical properties alone were required, for example, some other material would probably do the job better.

This Manual must differ from a report on a metal alloy family. Properties of reinforced plastics vary widely, for resins, reinforcements and fabricating methods all have important effects. Therefore, no concrete values can be given for strength, density or corrosion resistance. Also, design possibilities are many and broad, but hard to define. Resins and reinforcements come in many forms, all varying with the manufacturer. The molding techniques depend on the materials and change with the skill, equipment and habits of the molder.

We can only give indications of possibilities. The usual property limits are outlined, design conventions are given and some present and projected applications are presented.

Materials

Reinforced plastics are far from being standardized. Therefore, in order to consider and specify correctly, engineers should be familiar with constituent materials and molding techniques.

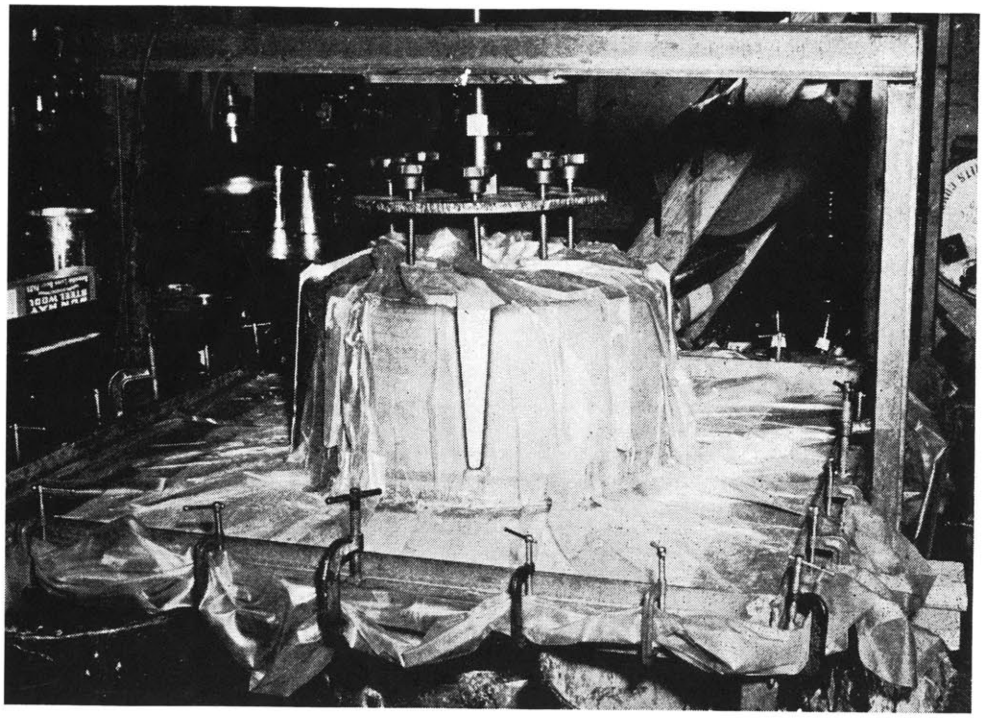
Resins

Polyesters are by far the most widely used resins. Phenolic, silicone and epoxy resins have been tried but are largely experimental now. All these resins are thermosetting. All have good wearing qualities, high strength and resistance to relatively extreme temperatures and chemical attack. While polyesters are surpassed by others on properties or costs, processing advantages outweigh these factors.

Polyesters are used in liquid form. Some suppliers market dry polyesters which are dissolved in liquid styrene before use. Setting, or polymerization, is started by catalysts added just before the liquid resins are put into a mold. Heat speeds up cure. Choice of catalyst depends on curing temperature.

Cured resins vary from soft and flexible to hard and rigid. Their electrical properties and chemical resistance are excellent, cured dimensions are stable, and a wide range of colors is possible.

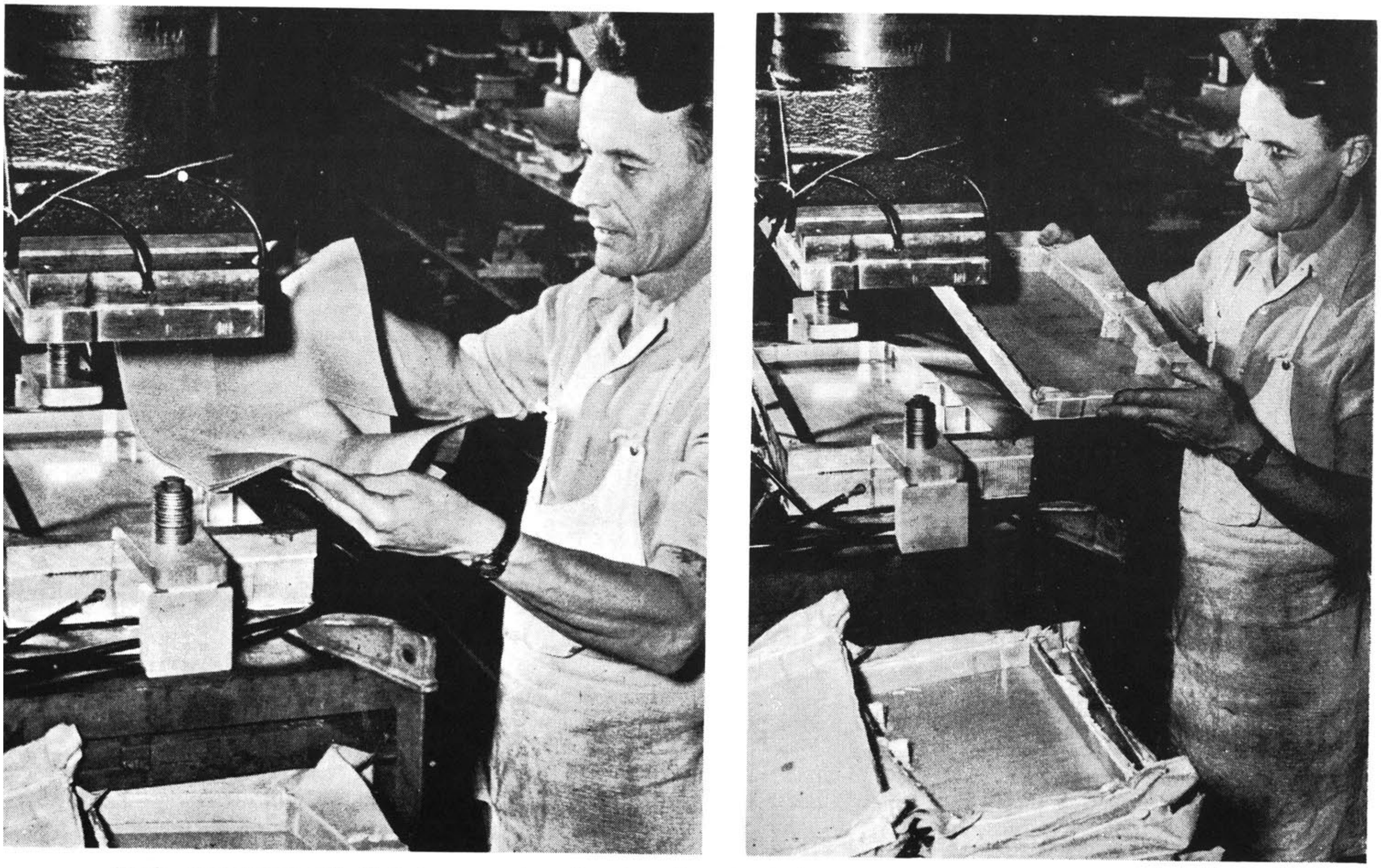
Two important considerations in formulating polyester resins are shelf life and get time. Shelf life is the time the resin remains stable after being prepared for use. Get time is the time it takes to set to a gel under molding conditions. Catalyst type and amount greatly affect both these characteristics.



In vacuum bag molding, cloth is laid over a form and impregnated with resin. The entire layup is covered, sealed and depressurized by a vacuum pump. Heat may hasten cure. (The Glastic Corp.)

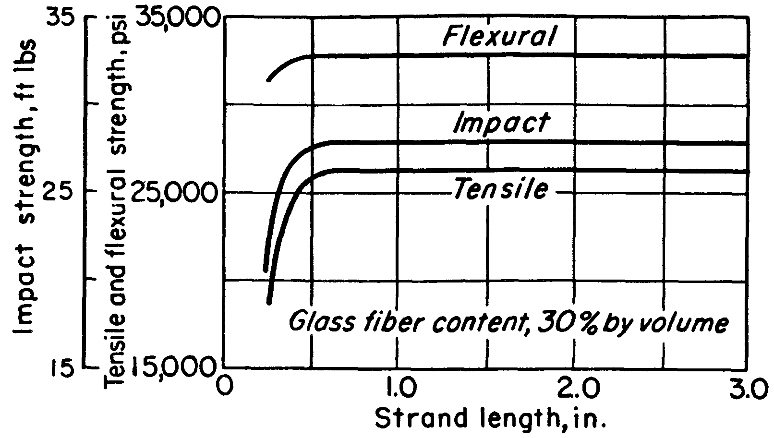
Viscosity and reactivity of polyester resins can also be varied. Viscous resins have good lay-up tack, increase film thickness in dip coating and laminating, give more stable suspensions and decrease flow before gelation. Low viscosity resins give faster penetration and impregnation, are easier to mix with catalysts, pigments and fillers, and free themselves of air bubbles quickly. Resin reactivity controls cure speed, heat of reaction and finished properties. In general, rigidity, heat-distortion point, heat resistance, shrinkage and dimensional stability of the finished property increase with resin reactivity. Casting, for example, requires low activity resin for low exotherm, low shrinkage and high impact strength. Post-forming requires low heat-distortion temperature, and hence less reactive resins. More reactive resin, with high distortion point, is used when it is necessary to quickly remove molded parts from hot molds without any distortion.

Resin selection also depends on size and thickness of parts, type and



Simple, shallow parts with filletted corners not needing close dimensional tolerances are molded by drawing resin impregnated cloth or mat into the mold. (Republic Aviation Corp.)

amount of fillers, temperature and heat dissipation rate of molds, and type and amount of catalysts. Basic commercial polyester types are: rigid, flexible, high heat distortion, low heat distortion, fast get time, slow get time, and fire resistant. Combinations are blended for special applications. Final resin choice often depends on molding experimentation.



Molding strengths are independent of glass-reinforcing strand length between ½ and 3 in. For handleability, 2-in. strands are usually used. (Owens-Corning Fiberglas Co.)

Epoxy resins, like polyesters, cure with little or no pressure. Their great adhesive powers give good bond between the plastic and glass fibers. Epoxy-glass materials are, therefore, stronger than polyester laminates. Chemical resistance is also better in some cases, especially with alkalies. Epoxies are 50 to 100% more expensive than polyesters, however. High adhesive power is also a disadvantage in making it difficult to separate finished products from their molds.

Silicones are promising for parts subject to elevated temperatures. Experiments on complex parts molded at 15 psi is encouraging. Silicones retain strength for long periods at 500 F, and for limited periods at temperatures up to 900 F. Resins are quite expensive, however.

Work is also being done with glass-reinforced, low-pressure phenolics. Their properties are similar to polyesters, except for electrical properties, where polyesters hold a definite advantage. Phenolics are considerably cheaper than polyesters and have better properties at elevated temperatures. The drawback to phenolics has been the high molding pressures required for sound parts, and the volatile compounds given off in curing. Several new phenolic compounds that cure at low pressures have recently been introduced, however. Northrup Aircraft engineers recently predicted that glass-phenolic, rather than glass-polyester, would be used in future supersonic airplane skins.

Fillers and Pigments

Commonly used fillers include products consisting mainly of clay, calcium carbonate and aluminum silicate. They give three advantages—improved surface finish, higher physical properties and reduced costs.

Polyesters have high cure shrinkage. This may produce a slightly raised fiber pattern on some surfaces, as well as craze marks or cracks in resin-rich areas. Inert fillers reduce shrinkage, so that crazing can be eliminated and a smooth, even surface obtained.

Certain physical properties can also be improved. Water absorption may be cut one-third, giving better wet strength. Flexibility is modified and finished parts are more rigid. Strength is increased slightly by filler concentrations up to 40% by weight, but larger percentages decrease strength. Chemical resistance is usually unaffected. Resin and filler manufacturers should be consulted when chemical resistance is of prime importance, however.

Most fillers cost less than polyester resins. Concentrations up to 50% by weight are used to extend resins. Specific gravity is increased by fillers. Since some fillers absorb resin in large quantity, a given filler weight concentration does not necessarily give a corresponding volumetric extension.

While the basic resins are clear, polyesters can be pigmented to any color from black to white. Organic, inorganic and metal oxide pigments are used. The pigment chosen must fit the resin, since some pigments accelerate or slow up resin cure.

Reinforcements

For all practical purposes, the materials we are covering here are exclusively reinforced with glass fibers. Paper, cotton and asbestoes have been tried experimentally, but glass has the best combination of strength and permanence. The various forms in which glass fibers are available fill the needs of most of the low-pressure laminates now being made commercially. The forms available are cloth, mats, glass roving, and preforms. The type of glass reinforcement chosen depends more on production problems and parts shapes than on the physical properties required in the part.

Cloths are classified by weave. In plain cloths, each warp and fill yarn passes over one yarn and under the next. Satin fabrics, most satisfactory in heavier grades, are made so that each warp and fill yarn goes under one and over seven yarns. These eight shaft satins give greater strength in laminates than plain weave fabrics. A third variation is unidirectional fabric. These are made with strong warp yarns and relatively few, weaker fill yarns. Such a construction gives maximum strength in one direction.

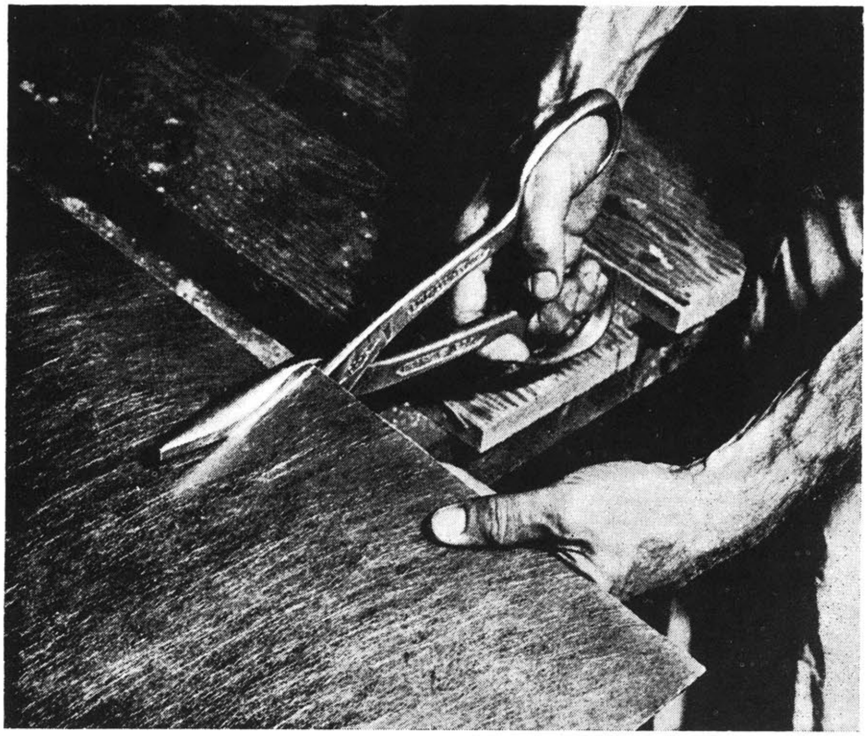
Glass is also available in mat form, which is cheaper than cloth. Mats are made of short fibers, pressed in layers and held with plastic binder compatable with the resins used. Mat is used to reinforce flat sheet and relatively shallow drawn or embossed parts.

A third form is glass roving. This consists of long, continuous strands. There are no cross threads. Roving is used as a reinforcement in a few special products.

The fourth type of glass reinforcement is preforms. These are made by preshaping fibers to the contour and thickness they will have in finished parts. Preforms lend themselves to complex pieces, where tailoring of mat or cloth would be wasteful. Parts with deep draws, severe flanges or heavy embossing are typical. Undercut pieces are not practical.

To make a preform, roving is cut in ½- to 2-in. lengths by a special machine, fed into an air stream, stripped of static electricity by an electronic field or a steam jet, mixed with liquid or powder binder and collected on a preform screen. The screen has the shape of a die for the finished part. Binder may also be sprayed on the screen as the fiber collects. An alternate method is to hand spray both binder and fiber on the screen. In all cases, the inside of the screen is held under vacuum to keep fiber and binder in place. Many automatic preforming setups are being used. Some even vary the fiber coat thickness or weight at different parts of the preform. The final operation is to bake the preform to set the binder.

In some parts which require extremely sharp variations in section thickness, combinations of mat and preforms are used.



Panels cut easily with shears or standard saws. The material can also be drilled with regular tools and fastened by bolts or adhesive. (Alsynite Co. of America.)

Machining in Brief

Blanking and Shearing: Press capacity is approximately one-half that required for metal. Edges are sharp with stock up to 3/32 in., fair up to 5/32 in., acceptable to ¼ in. Die clearances should be half those specified for steel. Shear gibs should be snug and blades sharp. It is not necessary to pre-heat the stock. Punched holes are smaller than the punch by 0.002 to 0.010 in., depnding on thickness and diameter. Blanked pieces will be larger than the die by 0.001 to 0.005 in. Stripping mechanisms requires two to three times the loading used for steel blanking dies to overcome tendency to grip extended punches. Die life between sharpenings is about one-half that for steel and three-quarters that for phenolics.

Drilling and Tapping: Rapid operation is achieved with much less power than for metals. Smooth holes are free from chipping and strong threads (one-third the strength of steel) can be obtained. Holes tend to be larger than the drill by about 0.003 to 0.005 in. (more if not well guided). Drill and tap wear are quite rapid on first few pieces, after which it tends to become stabilized. Carbide-tipped drills should be used in solid fixtures for production drilling. Tapping must be done carefully to avoid false cutting and severe weakening of threads. Automatic feed is essential on production work. Wet operation greatly prolongs tool life and eliminates dust. Vacuum dust removal is essential for dry operations on production scale. Drilling parallel to laminations must be done cautiously to avoid delamination, just as with phenolic laminates. Drill should be kept sharp and feed should not be forced. Faster drilling can be accomplished when it is possible to clamp opposite faces tightly.

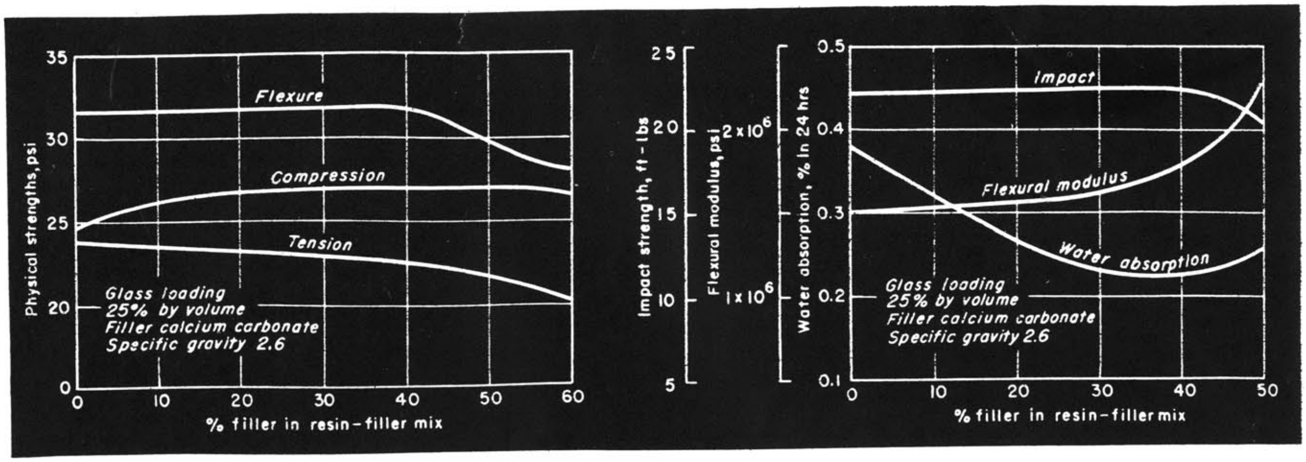
Band Saw Cutting: Smooth, accurate edges and fast cutting are obtained at extremely high blade speeds (5000 to 10,000 ft per min) in equipment such as Do-All Zephyr. Satisfactory edges requiring only light benching operations can be obtained at ordinary saw speeds. Very low blade speeds (300 to 400 ft per min) are recommended for longer blade life with standard machines. Standard coarse tooth metal cutting blades are satisfactory. Wavy or raker tooth types are recommended. Dust should be removed with vacuum pick-up where production operations are involved. Blade teeth will lose initial keen edge in first few inches of cut so that the saw is no longer useful for metal cutting. It will continue to cut satisfactorily for glass laminates for an hour or more of operation.

Rotary Cutting: Clean, smooth edges are easily obtained at high speeds. Wet cutting is far superior to dry. Greater speeds are possible, less power is required, and the dust removal problem is eliminated. Abrasive wheel cutting is faster than diamond or carbide blade cutting, and the cost of blade maintenance is appreciably lower. Rigid work support and wheel mounting are essential with an abrasive wheel to avoid hazardous and expensive blade breakage. Adequate safety hood must be provided. Diamond-edge stainless steel blade is recommended where the conditions prohibit use of abrasive wheel. Carbide-tipped saws will work satisfactorily for dry cutting. Sawing speeds are equivalent to those for phenolic laminates; much higher than for metal. Carbide dry cutting blade life will be about one-half that with phenolics.

Milling and Lathe Operations: Clean, smooth, accurate surfaces can be obtained at high speeds. Speeds and feeds recommended for brass are most satisfactory. High clearance and negative rake should be used on tools. Tools must be kept sharp to avoid crowding pressure against cutter with resultant inaccuracies and tendency to delaminate where cutting edge rises across the laminations. Carbide or diamond tools give better life than high-speed steel.

Routing: Routing is faster and more acurate than jig or keyhole sawing for medium-run cutting of irregular holes. High speed, low maintenance are achieved in production edging. Routing gives clean, accurate surfaces in edging. Bench filing is required after routing large holes. Routing must be done dry; dust should be removed. Carbide bits are essential.

(Glastic Corp.)



Properly incorporated fillers improve surface finish and physical properties and reduce material costs. In general, physical properties tend to increase with filler concentrations up to 40%, after which they drop off. Chemical resistance of laminates is generally not affected by filler. (Owens-Corning Fiberglas Co.)

Molding Methods

Molding methods depend on part size and shape, properties desired and planned production quantity. Reinforcements, and to a lesser degree resins, are chosen to fit molding methods.

Matched metal die molding is widely used for long production runs and for close tolerance parts. Molds are heated by steam, hot water, or more rarely, electricity. The preform, cloth or mat is put over the die. With complex parts, pieces can be cut from multiple layers of mat or cloth, and pie sections can be removed to fit deep ribbed sections. Trial and error may be needed to find the right cutout shapes. Pieces can be assembled on a layup jig, and stapled together to hold their shape. Layup dummies shorten production cycles, since the molds do not get a chance to cool. Lap joints in intricate layed-up cloth mat parts may cause section nonuniformities, however.

After the reinforcement has been put over the die, the carefully measured required quantity of resin is poured over it. Resin quantity is calculated on a weight ratio basis from the weight of the reinforcement. In some cases, reinforcement is supplied already impregnated with resin, so that the molder merely puts the glass in the heated molds.

The dies are closed slowly to avoid disturbing the reinforcement or entrapment of air bubbles. Cure times vary with mold temperatures, resins and part section thicknesses. After curing, dies are opened and the part is removed by rubber section cups, air ejection or slip rings. If distortion is noticed, parts are put in cooling jigs for permanent setting. Finally, flash is removed from edges. If the part is to be painted, it is cleaned with acetone and sanded to remove lubricants.

The same techniques are used for draw molding thin parts. Here several layers of impregnated mat or cloth are drawn down into the mold as it closes.

Any type of press capable of exerting 150 psi on the required projected area can be used. Pressures up to 300 psi are used on hydraulic presses.

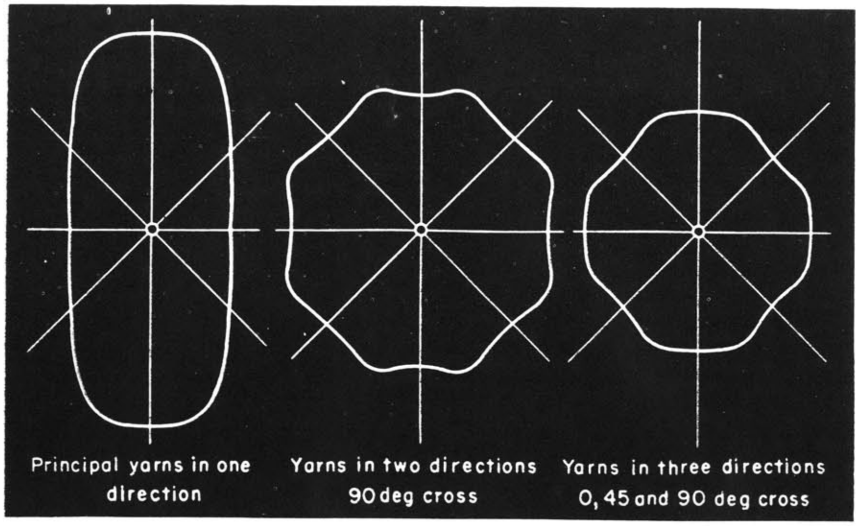
Die material depends on surface desired, production run length and complexity of parts. Tool steel, Kirksite, aluminum and Meehanite cast iron are most commonly used. Kirksite is cheapest, is cast to close tolerances and scraped clean so that little machining is needed. Use only under low temperatures and pressures and for short production runs are disadvantages of Kirksite. Aluminum, though more expensive, allows higher temperatures and pressures and longer production runs. Meehanite, a fine grain cast iron, can be flame hardened around die edges to cut off flash. It is more costly than either Kirksite or aluminum, gives high gloss surfaces, and lasts almost indefinitely in quantity production. Tool steel is the most expensive die material, and the best. It can be polished to mirror finish to give excellent part release. Hard chromium plated steel dies give even better finish and part release. It should be noted, however, that part finish also depends on die temperature; smoother surfaces are obtained with hotter dies.

Where close tolerances are not required, production is not high enough to justify matched metal dies, or where parts are too big or complex to make with machined metal dies, bag or contact molding can be used. The same types of reinforcement can be used, although hand-layed mat and cloth are more usual than preforms. There is no male die in this work. The reinforcement can be impregnated with resin before or after it is put into the mold. In contact molding, the glass is then rolled to eliminate air bubbles and to press the layers together. In bag molding, a thin vinyl blanket is placed over the resin-impregnated reinforcement in the mold. The edges of the blanket are clamped to each other or to a metal backing. This makes an airtight enclosure, which is evacuated so that the vinyl presses down evenly on the whole surface. The part is cured in an oven. Thickness tolerances are wide with contact and bag molding, and surfaces are much rougher than with matched metal dies.

Two different types of mat and preforms are used. These are classified by the binder resins. Highly soluble binders are used for parts cured at room temperature or relatively low temperatures. These binders dissolve in the laminating resin to some extent. This allows the mat or preform to take the required shape without great pressure. Skylights, boats, automobile bodies and a great many phototypes use high solubility binders. Heated, matched metal molds require low solubility binders. The resin is hotter here, and its viscosity is lower. This allows it to run through the reinforcing fibers and fill the mold cavity. The low solubility resin remains firm enough during molding to prevent the resin from tearing or washing the glass fibers out of position to leave resin-rich, weak areas in the finished product.

Work has been done with post-forming. Some resins have the property of softening somewhat when heated after molding. In this condition, some forming can be accomplished before the part cools to final set. This process is still pretty much in the development stage.

In most of these methods, resin and reinforcement are mixed in the mold. There is one other technique, however, in which mixing is done before the compounds get to the mold. Polyester-glass molding compounds are still comparatively new and commercially small. Their importance is growing. These compounds, composed of polyester resin and glass fibers up to 2 in. long, are suitable for compression, transfer and injection molding. With the right techniques, good distribution of the fibers can be maintained throughout the part. With a glass content of only 30% by weight, parts molded by these methods are not as strong as conventional glass-reinforced polyester pieces. More intricate shapes can be made at lower costs, however. Electrical properties are not harmed by the increased resin content, and many electrical parts are made in this way. Glass also gives dimensional stability. [See *Materials & Methods,* Jan. 1953, p. 87.]



Diagrams show directional strength control possible with cloth laminates. Unidirectional cloth can be laid-up with principal yarns (warp) parallel, crossing at 90 deg, or in a three-way cross. Square woven and satin fabrics may have warps and fills in line or in alternate layers crossing at 45%. (Owens-Corning Fiberglas Corp.)

Properties and Design

Specific property data and hard and fast design rules or conventions are difficult to find, since properties are not well defined and experience in most applications is lacking. Strength, chemical resistance and temperature limits vary with the type and supplier of the resin. Molding variables also have effects. Thus, there are no reliable property charts for finished materials. Even if there were, the absence of practical experience with many products and the absence of good nondestructive testing methods would prevent the engineer from designing to the highest property values. Nevertheless, general property indications can be given, together with such design conventions as have evolved from molding procedures and the present short experience.

Cooperation between molders, designers and users is essential. Experience and experiment are the only reliable guides in deciding on reinforced plastics for a piece and in designing the piece. Molders must be given complete information on how and where a part is to be used, and detailed specifications should not be set up until some actual parts are made and tested.

Mechanical Properties

Within practical ranges, tensile strength, flexural strength and impact strength vary directly with the percentage of glass in the laminate. This is true of mat, preform and cloth reinforced materials. Within ½- to 3-in. limits, fiber length has no effect on flexural, tensile or impact strength.

Unlike properly molded mat and preform reinforced parts, cloth reinforced products may have definite directional properties in the flat direction. Plain weave fabrics give a uniform strength pattern through 180 deg. With contact molding and vacuum laminating, air bubbles are easy to remove and a homogeneous, strong product is obtained with plain weave fabrics. Long shaft satin weave fabrics are best used where light weight and high strength in all directions is required. With thick satins, high-strength laminates are easier to make, since layup costs are reduced.

Unidirectional fabrics are recommended to give maximum strength in one direction. They are valuable where the loads can be definitely established for the finished part. Unidirectional fabrics can also be used to give additional strength or impact resistance in local areas. They give extreme strengths with minimum weight. Because unidirectional fabrics must be cross-laminated, however, they raise costs by increasing hand labor involved.

The highest over-all strength properties are found in the thin glass cloths and in laminates employing them, at least on the outer stressed surfaces. Over-all strength decreases as fabric thickness increases. The diminishing effect of increased thickness is greatest in compression. Impact strength, however, varies directly with the thickness. That is, thicker fabrics have higher impact strengths.

Many parts are built up of several layers of mat and/or cloth. Since each type of cloth has its own modulus and strength qualities, uneven cooling after molding could conceivably cause warping. If the layers are put on so that the reinforcement is symmetrical around the neutral axis, this danger is removed. Such an arrangement is important when dimensional stability is desired.

One problem is low modulus of elasticity in flexure. To get the same resistance to bending as steel, material must be over twice as thick. This reduces the weight advantages and increases cost. Where flexural loads are involved in parts requiring minimum weight, sandwich construction can be used. The laminated skins are fully stressed in tension and compression and the core serves primarily as a spacer. Properly designed, sandwich construction offers maximum rigidity with minimum weight. The primary limitations are that they possess low impact resistance because of stiffness and thinness of the surface laminates, and they are relatively expensive to fabricate because of the hand labor involved.

Table 1—Properties of Cloths

Cloth	Yarn	Construction	Thickness, In.	Weight, Oz/Sq Yd	Break Strength, Lb/In. Width	
					Warp	Fill
			SQUARE-WOVEN FABRICS			
A	450-1/2	40 x 39	0.003	2.09	100	70
B	225-1/3	42 x 32	0.007	6.0	250	200
C	225-2/5	28 x 16	0.015	12.20	450	350
			UNIDIRECTIONAL FABRIC			
D	Warp— 225-3/2 Fill— 450-1/2	48 x 30	0.009	8.90	610	56
			LONG-SHAFT SATIN WEAVE FABRICS			
E	225-1/3	57 x 54	0.0085	8.90	310	310
F	225-2/2	60 x 56	0.013	12.40	390	380

Table 2—Typical Properties of Cloth Base Polyester Laminates

Cloth (See Table 1)	Tensile Str., Psi	Compressive Str., Psi	Flexural Str., Psi	Bearing Str., Psi	Shear Str., Psi	Modulus in Flexure, Psi	Izod Impact Str., Lb/In.
A	40,400	36,200	57,100	36,600	18,500	2,860	16.8
B	40,600	25,300	53,200	46,800	19,300	3,340	19.0
C	35,400	15,400	41,100	31,900	18,100	2,360	30.7
D (Parallel)	84,600	47,100	107,400	41,100	26,800	5,370	52.2
D (Cross)	47,800	39,800	68,800	43,300	20,300	2,760	27,600
E	36,800	35,900	61,200	41,600	18,600	3,220	19.3
F	49,400	26,900	57,900	34,300	19,000	3,250	25.4

Data courtesy Owens-Corning Fibreglass Corp.

NOTE: The cloths in Table 1 are typical. The table is not all-inclusive.

The laminate properties in Table 2 are based on a particular resin and cloth finish. They are given for illustration purposes only.

Temperature, Corrosion and Moisture

Strength, including impact strength, improves as the temperature goes down, even down to —110 F. Strength decreases with rising temperature. In air, temperatures up to 250 F can be taken continuously, with intermittent temperatures up to 300 F. Continuous temperature is limited to 180 F in water or alkalies. Resin manufacturers should be consulted for the heat distortion point of each resin, however.

Since glass fibers do not shrink or stretch under moisture change, have a low thermal expansion coefficient, and are strong enough to resist expansion by the resin, laminates are quite dimensionally stable. Thermal expansion of the material is about 16 x 16^{-6} per deg F. This changes slightly with glass content. It is close to the expansion rate of aluminum alloys.

Thermal transmission rate for male laminates is about 1.5 Btu/hr/sq ft/in./deg F. It increases directly with the volume percentage of glass.

Weathering tests over a period of time equivalent to several years of exposure under the severest conditions have indicated no significant effect on laminate strengths other than a slight yellowing of the plastic material. When immersed in water for 14 days and tested while wet, these laminates retain 80% of their initial dry strength.

Reinforced plastics have good resistance to many corrosive chemicals. Many acids, solvents and weak to medium bases can be handled successfully. An accompanying table lists resistance of reinforced plastics to common chemicals.

Machining, Joining and Finishing

Glass-reinforced polyester can be machined, in general, with standard steel working equipment. They are similar in machining characteristics to canvas-base phenolics.

Joints are made with polyester resin adhesives. Lap joints of 200- to 500-psi strengths can be obtained. These are adequate where prying, peeling and shock are negligible. The only really strong cemented joint is one made by pressing one tube inside another. Before bonding, surfaces should be lightly sandblasted. Bonds to metal are usually poor.

Bolted joints are commonly used when molded sections must be joined. Flanges are reinforced by

Table 3—Physical Property Requirements, Structural Glass-Reinforced Polyester (U. S. Air Force Specification 12049).

Federal Specifications L-P-406 Method No.	Property and Test Conditions	Requirements
*1031	Ultimate strength, flexural, flatwise, psi	45000
1031	Yield strength flexural, 0.2% offset, psi	40000
1031	Tangent proportional limit, flexural, psi	25000
1031	Modulus of elasticity, flexural, initial, psi	2.5 x 10^6
1011	Ultimate strength, tensile, psi	35000
1011	Yield strength tensile, 0.2% offset, psi	25000
1011	Modulus of elasticity, tensile, initial, psi	2.5 x 10^6
1021	Ultimate strength, compressive, edgewise, psi	25000
1021	Yield strength compressive, edgewise, 0.2% offset, psi	24000
1021	Modulus of elasticity, compressive, edgewise initial, psi	2.5 x 10^6
1071	Impact strength, edgewise, notched Izod, ft lb per in. notch	7
2021	Flammability, in. per min (max)	1
7031	Water absorption, max, 24-hr immersion	1.0%
7031	Thickness increase, max, 24-hr immersion	0.5%
1081	Rockwell M hardness	95
	PROPERTIES AT 160 F:	
1031	Ultimate strength, flexural, flatwise	23000
	Modulus of elasticity, flexural, psi	1.9 x 10^6

* *Plus 10% Styrene Monomer.*

extra layers of glass cloth or mat or by metal inserts. These metal inserts can be molded into the material without difficulty.

Surface finish may be somewhat of a problem, particularly where shiny solid color finishes are desired. These materials do not have outstanding abrasion resistance. No finish has yet been developed to give them enough surface hardness to compete with metals in places where abrasion is encountered. Smoothness can be obtained on molded surfaces and cut edges, however, by coating with polyester resin.

Electrical Properties

For electrical applications, the low loss factor, good arc resistance and high dielectric strength at high frequencies of reinforced plastics are valuable properties. According to manufacturers, electrical grades of glass-polyester are competitive in price with cotton filled phenolics, but have greater impact strength, arc resistance, heat resistance, dimensional stability and moisture resistance.

Shapes and Tolerances

There is no size limit on parts. Parts made in matched metal molds are restricted by the size of presses, but bag or contact molded pieces have no such restrictions.

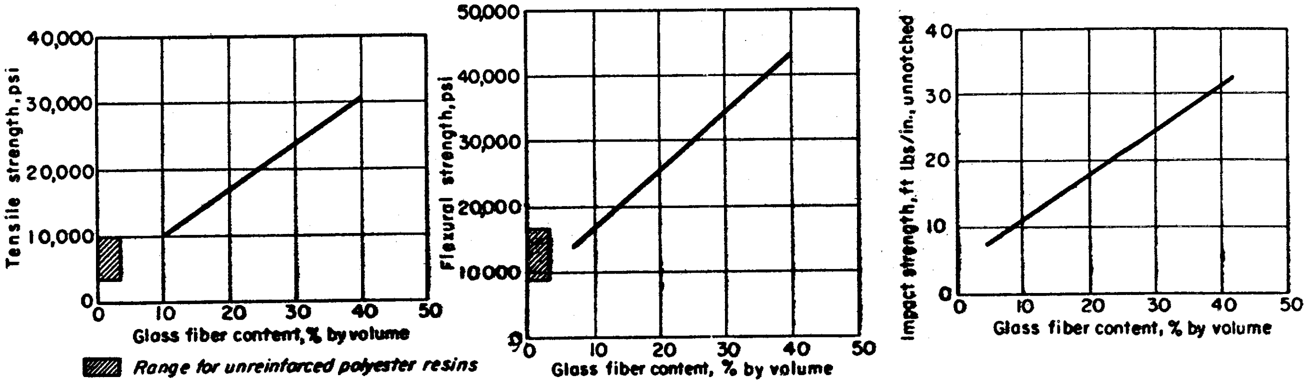
Any shape can be made that can be taken out of a mold. Undercut parts must be made in pieces, for example. It is advisable to keep 1/8- to 1/4-in. radii on all corners. Thick sections should be avoided, as should abrupt section changes. Deep indents and ribs can be made if these conventions are followed. Side walls should have a minimum draft of 1 deg for shallow parts and 3 deg for deep parts.

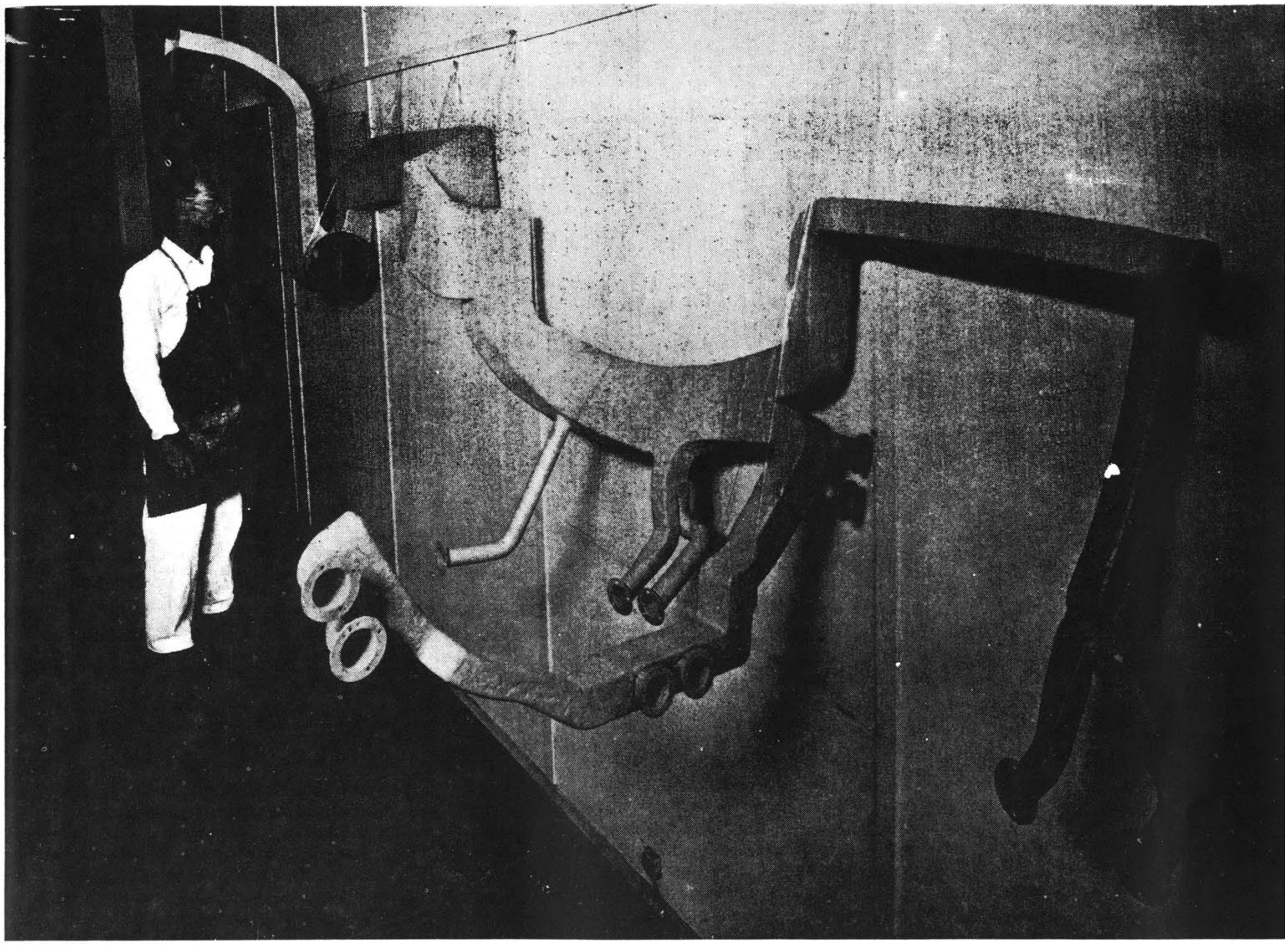
Part tolerances depend on mold tolerances and shrinkage. One molder suggests that 0.1 in. in 24 in. is a reasonable specification. Biggest uncertainty arises from: (1) a molded part shows different shrinkages on each dimension; and (2) these shrinkages are not exactly predictable. Shrinkage on each dimension is very nearly constant, however. Once a mold is made, parts show little dimensional variation.

Applications

Over half of the glass-polyester parts now being made are for military applications. It would be impossible to publish a complete list of major applications, even if such a list could be made up. In the following section, a limited number of interesting applications are mentioned. In each case competitive advantages are given. This may give the reader a better idea of the possibilities for reinforced plastics in his own product.

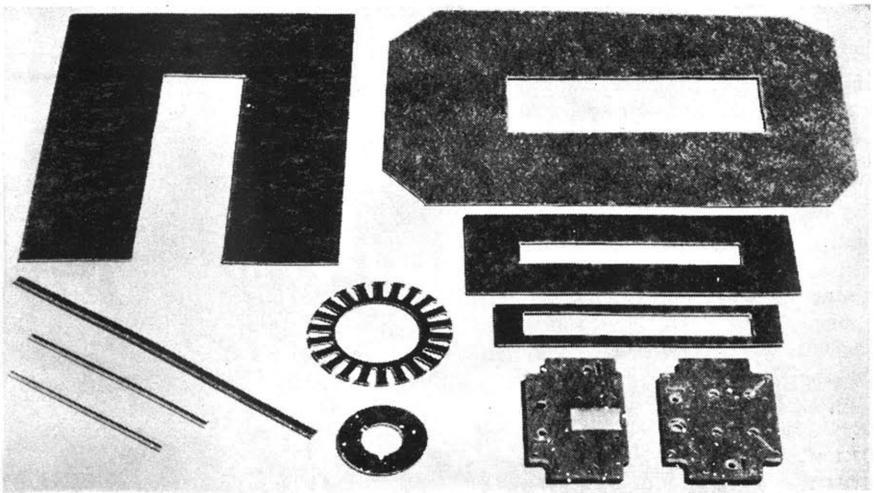
Tanks, pipe, hoods and ducts are made of these materials. The combination of corrosion resistance and


For practical ranges, tensile, flexural and impact strengths vary directly with the volumetric percentage of glass in mat and preform moldings. All other things being equal, a study of resin properties will indicate properties in the finished laminate. Impact strength of unreinforced resins is comparatively low, and is omitted for clarity at right. (Owens-Corning Fiberglas Corp.)



Complex airplane ducting can be molded comparatively easily, without the expensive tools that would be needed for aluminum. Reinforced plastic also saves weight. (Owens-Corning Fiberglas Corp.)

strength is the big selling point. Pressures contained cannot be very high, unless some seepage through the pores can be tolerated. Applications have been made in processing and electroplating in chemical, paper, textile, metal finishing and allied industries. Large duct systems carry away fumes from automatic pickling and phosphating machines. A recent job includes 500-gal tanks and necessary pipe and fittings for a laboratory waste system. Truck water tanks have been successful, with light weight and rust resistance the big advantages. Crude oil tanks, bolted together in sections, resist hydrogen sulfide, salt water and electrolytic action. Equipment which must be cleaned thoroughly and requires an enamel smooth surface is not fair game, however. The glass-plastic sur-



Glass-filled polyester insulating material is cold punched in thicknesses up to 1/4 in. (Glastic Corp.)

Table 4—Typical Corrosion Resistance

Reagent	Temperature	% Change Thickness After 1 Week, %	% Change Weight After 1 Week, %	Visible Effect
Sulfuric Acid	10% Room	+0.23	+0.018	Sl. surface attack
Sulfuric Acid	10% Steam bath	+33.0	+14.8	Badly attacked
Sulfuric Acid	96% Room	—	—	Completely broken up
Nitric Acid	10% Room	+0.28	−1.63	Unchanged
Nitric Acid	10% Steam bath	+1.8	−11.9	Slight attack
Nitric Acid	70% Room	+19.0	+23.9	Badly attacked
Hydrochloric Acid	10% Room	+6.2	−1.57	Unchanged
Hydrochloric Acid	10% Steam bath	+9.5	−6.92	Sl. surface attack
Hydrochloric Acid	36% Room	+2.0	−0.89	Cons. surface attack
Acetic Acid	99% Room	+1.1	+0.75	Slight surface attack
Acetic Acid	10% Steam bath	+20.0	−7.48	Cons. attack soft
Sodium Hydroxide	10% Room	+2.5	−3.77	Sl. surface attack
Sodium Hydroxide	10% Steam bath	+51.0	+29.0	Swollen soft cons. attack
Sodium Hydroxide	40% Room	−0.6	−0.87	Cons. surface attack
Zinc Chloride	10% Room	+0.4	+0.20	Unchanged
Zinc Chloride	10% Steam bath	+1.0	+0.62	Unchanged
Water	10% Steam bath	+2.1	+1.2	Vsl. surface attack
Methanal	10% Steam bath	+1.2	+1.69	Unchanged
Butanal	10% Steam bath	−3.7	+0.12	Unchanged
Butanal	10% Steam bath	+3.6	+2.9	Vsl. surface attack
Ethyl Acetate	10% Room	+3.6	+2.87	Sl. surface attack
Butyl Acetate	10% Room	+1.3	+0.086	Unchanged
Butyl Acetate	10% Steam bath	+11.0	+7.6	Slight surface attack
Acetone	10% Room	+5.7	+5.08	Sl. surface attack
Cyclo Hexane	10% Room	Unch.	+0.09	U. sl.
Cyclo Hexane	10% Steam bath	+100%	46.3	Badly attacked soft
Tetrachlor	10% Room	−1.8	+3.57	Vsl. surface attack
Tetrachlor	10% Steam bath	−0.5	−4.2	Sl. surface attack
Tetra Chlorolirium	10% Room	+1.0	−3.27	Sl. surface attack
Tetra Chlorolirium	10% Steam bath	+7.3	+5.79	Sl. surface attack

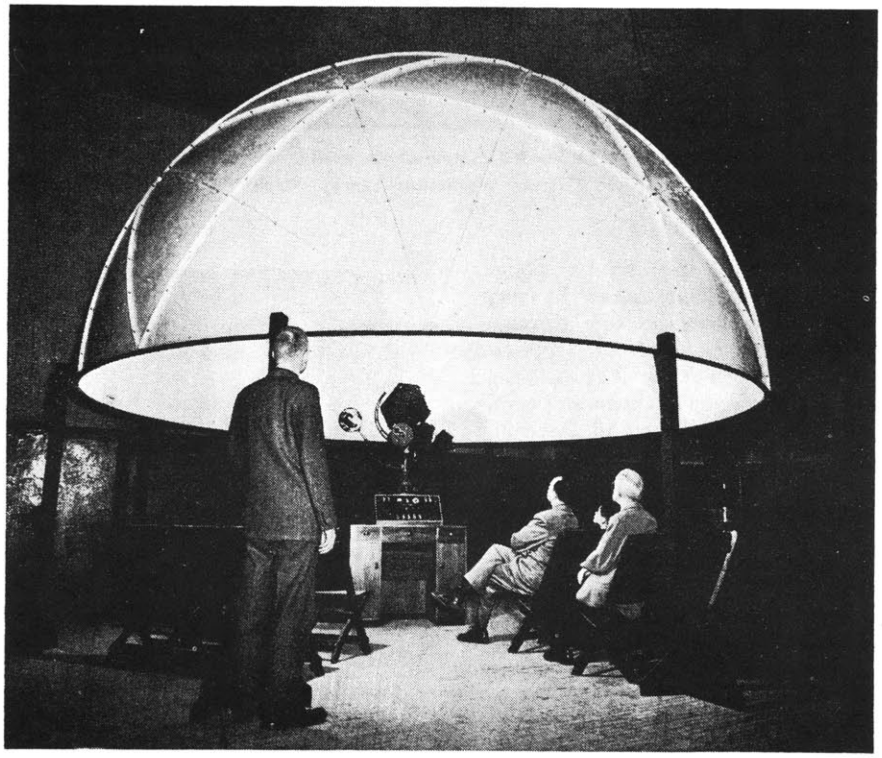
Tests made by Shawinigan Chemical Co. on glass-mat reinforced filled polyester resin produced by Molded Resin Fiber Co.

face retains dirt.

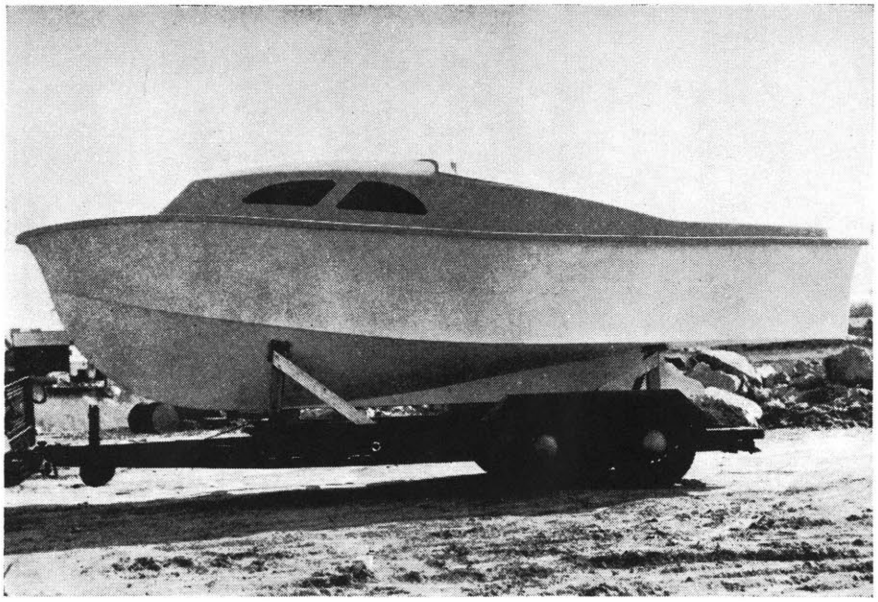
Trays and tote boxes made of reinforced plastics are light, strong and chemically resistant. They are easy to make, but cost more than similar metal products. In some cases, glass-plastic has not been durable enough. Deep trays, for example, were made too thick and lacked resiliency so that they broke in hard usage. Thinner walls and metal wire reinforcement at the top edges may be the remedy. Materials handling trays for bakery trucks are made in quantity. Pans and trays for water evaporation and chemical handling are also in commercial production.

Radomes were one of the first applications, and are still important. The material is strong enough to withstand the air pressures in aircraft applications. Corrosion by salt water and rain is no problem. Most important of all, glass-polyester is transparent to electromagnetic radiation. Solid and honeycomb structures have been used. Probably no other material could do the job. Some of the largest glass-polyester pieces made are radomes.

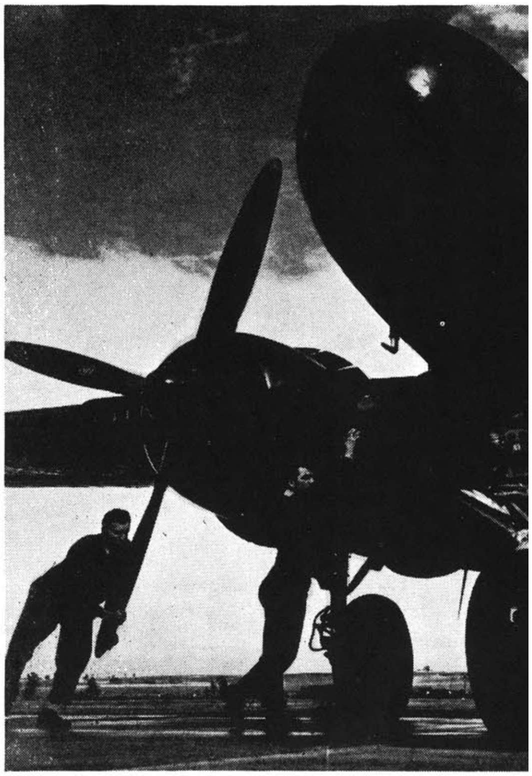
Some work has been done on ma-



Planetorium dome was molded in sections and bolted together. Light weight and easy molding to curved contours are selling points. (Winner Manufacturing Co.)



One-piece boat hulls resist corrosion, sunlight, worms, termites and rot. Light weight and reasonable cost are other advanages. (Beetle Boat Co., Inc.)



Radomes are an extremely successful application. Strong molded reinforced plastic skin is transparent to radar waves. (Owens-Corning Fiberglas Corp.)

Table 5—Typical Minimum Properties of Electrical Insulation Glass Reinforced Polyester

Property	Standard	Flame Resistant
Flexural strength, psi, min	20,000	34,000
100 hr at 302 F	20,000	32,000
Modulus of elasticity, psi, min	1.3 x 10^6	2.84 x 10^6
Impact strength, Izod, flatwise, ft-lb/in. min	12.0	19.2
100 hr at 302 F	12.0	25.0
Tensile strength, psi, min	10,000	17,000
Compressive strength, psi, min	33,500	53,000
Hardness, Rockwell M, min	85	90
Water absorption, %, max	0.60	0.75
100 hr at 302 F	1.60	1.75
Shrinkage—100 hr at 302 F, shrinkage shall not exceed 1.0% in any direction.		
Dielectric strength, v/mil, min[2]	300	250
After 100 hr at 302 F	300	250
Arc resistance, seconds, min[2]	125	40
Insulation resistance, after 5 days at 125.6 F+3.6 F	—	5
Warp or twist—standard conditioning and 100 hr at 302 F, shall not exceed the following:		

Thickness, In.	Warp or Twist, % of Length, [1]Max
Over 1/15 to 1/4 incl	1.0
Over 1/4 to 3/4 incl	0.5
Over 3/4 to 1 incl	0.25

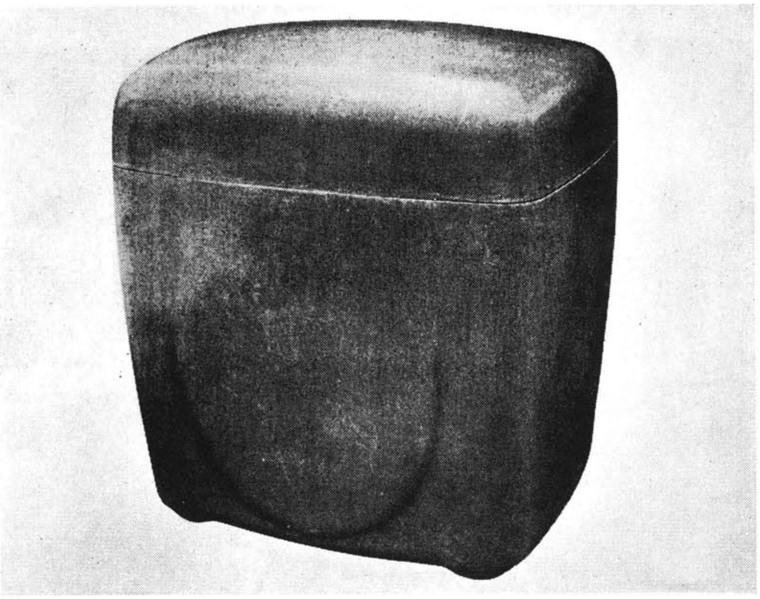
Referee Methods:	
Conditioning	ASTM D229
Flexural strength	ASTM D229
Modulus of elasticity	ASTM D790
Impact strength	ASTM D229
Tensile strength	ASTM D229
Compressive strength	ASTM D229
Hardness	ASTM D229
Water absorption	ASTM D229
Arc resistance	ASTM D495
Dielectric strength	ASTM D229
Insulation resistance	ASTM D257[3]
Shrinkage	ASTM D709
Warp and twist	ASTM D709

NOTES: [1] *Length of dimension along which warp or twist is measured (on basis of 36-in. length).*
[2] *After conditioning for 48 hr at 122 F, unless otherwise indicated.*
[3] *After specified conditioning, test shall be conducted at 125.6 F and 100% R H using tapered pin electrodes and applied voltage of 200 v.*

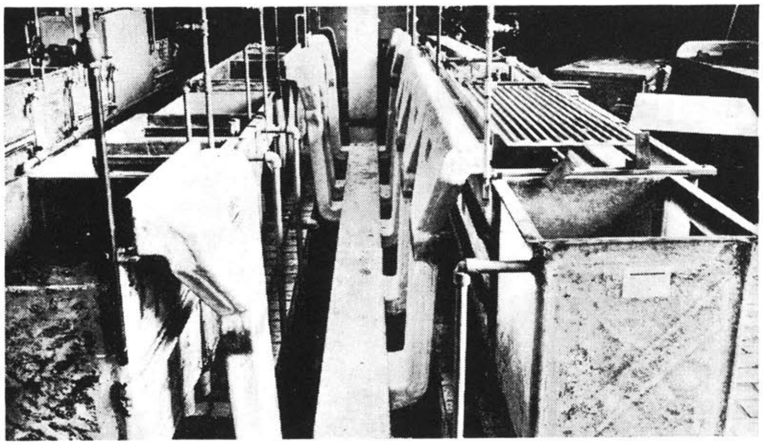
Adapted from General Electric Co. Specifications

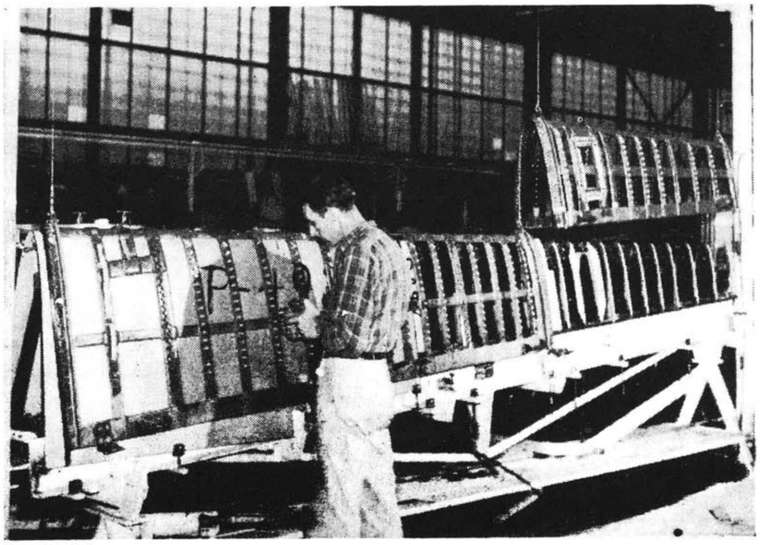
chine housing, particularly to replace aluminum castings. A photoelectric engraver cover provides good insulation to the machine, and grounds out electrical interference through a molded-in copper screen. Reinforced plastic cases are being studied by military authorities for nonportable typewriters. These would replace wood and metal at 50% weight saving. Unless weight, electrical insulation or corrosion resistance is of prime importance, however, metal housings will almost always be cheaper.

A big use of glass-reinforced polyesters is in electrical insulation, primarily as a replacement for phenolics. This replacement is strictly on the basis of lower cost and/or better properties. Compression molded parts and parts stamped from sheet are used. The higher cost in relation to canvas and paper-phenolics is offset by greater strength, impact resistance rigidity and by the ability to take higher operating temperatures and temporary overload temperatures without blistering, embrittlement or shrinkage. More vibration can also be taken. Glass-polyester is also easier to punch into intricate shapes than asbestos-phenolics.

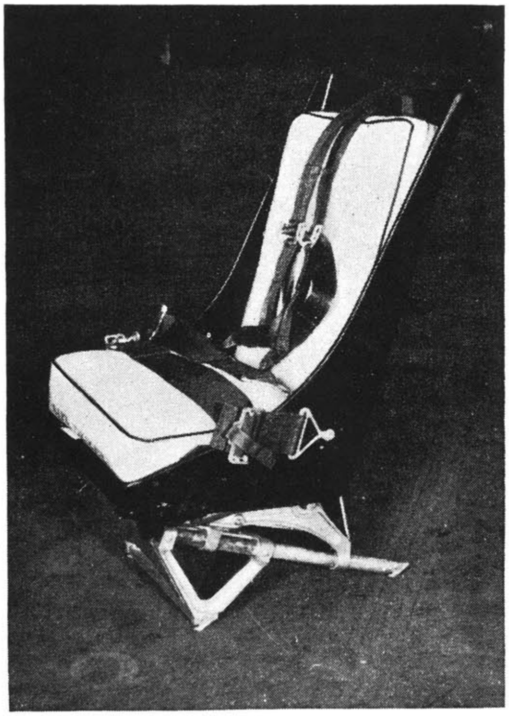


Navy two-piece loudspeaker housing is example of preform molding. The unit out-performs metal cabinets acoustically. (American Cyanamid Co.)





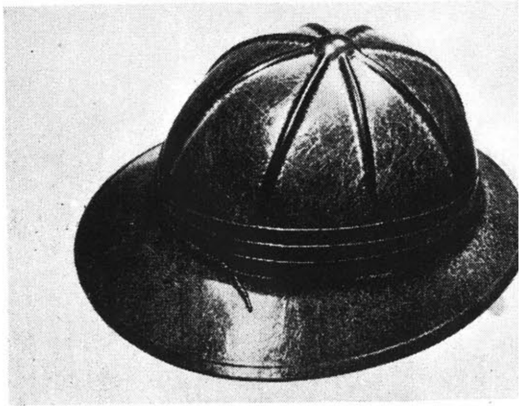
Patterns and fixtures for aircraft parts are molded of glass-polyester in intricate shapes quickly, easily and economically. (Republic Aviation Corp.)



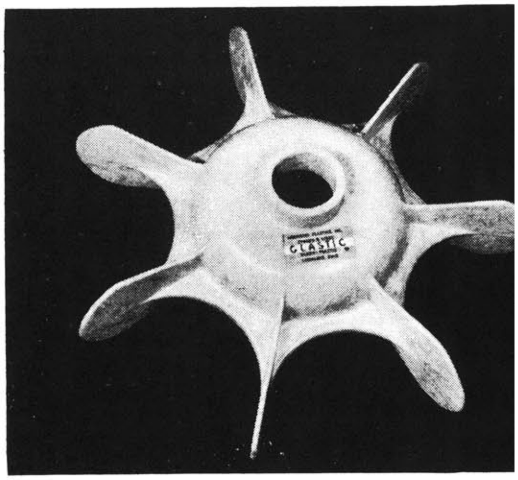
Airplane seat is outstanding for light weight and strength. Cloth and mat reinforcement are used. Riveted aluminum seats were heavier and more expensive. (DeHavilland Aircraft of Canada Ltd.)

In Class B motors, glass-polyester end laminations insulate coil turns without becoming brittle in service. (Glastic Corp.)

Glass-reinforced polyester track rail support plates have the required strength, corrosion resistance and resiliency. (Dynakon Corp.)



Safety helmets and even military body armour have been molded in glass-polyester. Light weight and high strength are valuable in these cases. (Auburn Button Works)



Westinghouse blower fan was switched to reinforced plastic from aluminum, cast iron, malleable iron, and bronze. Low inertia and corrosion resistance are desirable. Cost was lower than for bronze, malleable iron and sand cast aluminum. Costs were about equal for permanent mold aluminum. Unmachined die cast aluminum was slightly cheaper than reinforced plastic. (Glastic Corp.)

In electric motors and generators, slot sticks, slot cell bottom spacers and intercoil separators, armature end laminations, coil end washers and coil head insulation are being converted to this material. Electrical shim stock, electromagnet intercoil spacers, control finger panels, transformer spacers and terminal locks are also good applications. Moisture and tracking resistance are important in these spots. The material is used in chromium plating anti-saggers. Here it resists attack by the bath and retains its strength, rigidity and insulating value.

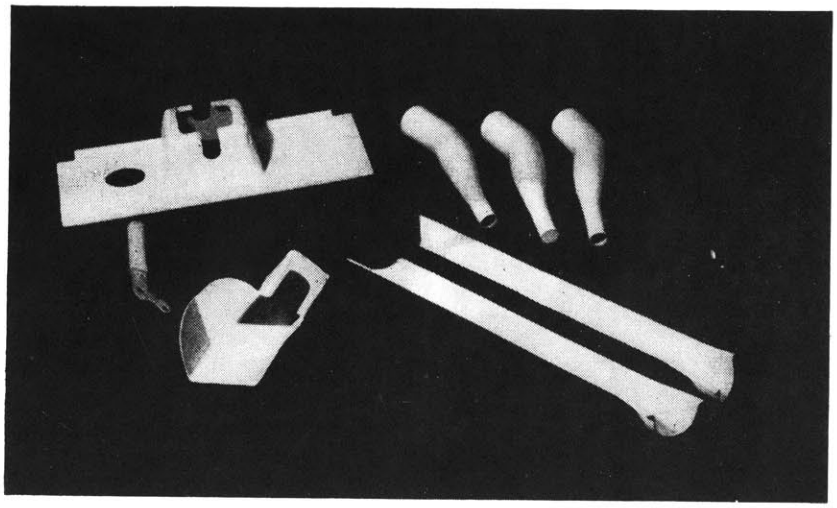
Ducts for the B-47 jet bomber have been molded from preforms. Weight saving was one advantage over aluminum. In addition, molding of the complex duct shapes was easier. Special tools and fixtures would have been needed to make aluminum ducts. Heating and ventilating ducts and the fuel-vent system are now made of reinforced plastic. Junction boxes and most of the safety equipment are other B-47 applications. Other military applications are crash helmets and bulletproof vests. Strength and light weight are the desirable properties in these products.

Two of the largest fields of application are in furniture and architectural materials. In utilitarian industrial and military shelters like plane housings and refrigerator buildings, light weight, corrosion resistance, strength and, to some extent, heat insulating value are required. In some places unpigmented translucent material is used in windows. A soft diffuse light is admitted and breakage is eliminated. The same properties are valuable in lamp shades. The ability of the material to be molded easily into complex, interesting shapes has encouraged its use in chairs and corrugated and patterned wall panels and screens.

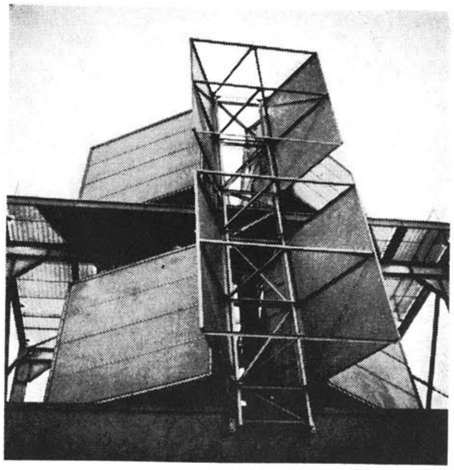
Inner door liners for commercial beverage coolers are being molded successfully. Finishing problems have so far stood in the way of similar domestic refrigerator liners.

A very successful application has been in small boats. The material is impervious to corrosion by salt water, sunlight, worms, termites, barnacles and rot. It can be molded easily into any shape the hull designer wants. The light weight of glass-polyester hulls is also an advantage. Many of these boats are used by civilians and by the armed forces.

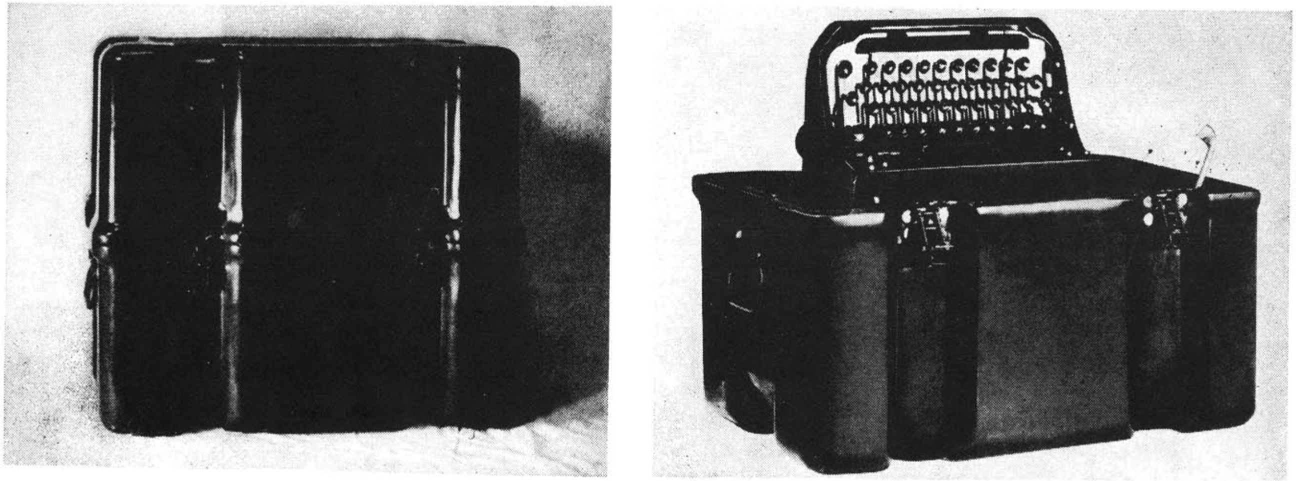
A recent, well publicized application is car bodies. Only custom-made, or special, low-production bodies are being considered. The material is strong enough to make a good body. Its big advantage is that relatively cheap molds are required for a given shape, so that custom bodies do not have to bear the cost of expensive dies required with metal. Thus, a



Aircraft ducting and inclosures of glass cloth-polyester are being used in increasing quantities. Weight advantage is gained over aluminum. (Flexfirm Products)



Strength, corrosion resistance and electromagnetic transparancy are all required in fronts for radio relays. (American Telephone & Telegraph Co.)



Reinforced plastic case for nonportable typewriter is under consideration by the military to replace wood and metal case at 50% weight saving. (Winner Manufacturing Co.)

new field of comparatively low-priced special bodies is opened up.

Another automotive use is in die models and short-run stamping dies. These dies do not last as long as alloy steels, of course, but are much cheaper and easier to make.

A number of other applications are in the tooling up stage or have just gone into production. Light weight bath tubs for house trailers, loud speaker horns, shower stall bases and liners for ice chests and frozen food containers are examples. Pressure containers for dispensing hot and cold beverages are in the same class. Another candidate is table top and panel material made by molding the material around Balsa cores.

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Auburn Button Works
Bakelite Co.
Beetle Boat Co.
Boeing Airplane Co.
Chemical Corp.
Ciba Co. Inc.
Cordo Molding Products, Inc.
Dynakon Corp.
Fabricon Products, Inc.
Ferro Corp.
Flexfirm Products
General American Transportation Corp.
General Electric Co.
Glass Fibers, Inc.
Glasspar Co.
Glastic Corp.
Molded Resin Fiber Co.
National Advisory Committee for Aeronautics
National Bureau of Standards
Northrup Aircraft, Inc.
Owens-Corning Fiberglas Corp.
Plaskon Div., Libbey-Owens-Ford Glass Co.
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Reinforced Plastics Consultants & Engineers
Republic Aviation Corp.
Rohm & Haas Co.
Smith and Stone Ltd.
Society of the Plastics Industry
United States Plywood Corp.
United States Rubber Co.
Universal Molded Products Corp.
Winner Mfg. Co.
Wizards Boats, Inc.
Zenith Plastics Co.

Frontispiece courtesy of Winner Mfg. Co., Owens-Corning Fiberglas Corp., Republic Aviation Corp. and Glastic Corp.

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APPENDIX C

Letter of inquiry and representative organizations in the plastics field

This is the body of a letter sent to twenty-two major organizations in the plastics field:

As a graduate student in architecture at MIT, I am exploring the possibilities of incorporating plastics in the design of an industrialized house (a house whose components are factory-produced and then assembled at a specific site). There is a great limitation in studying such a broad problem within the short period of time allotted me, and any comment you might offer on the following general inquiries would contribute towards making this project a worth-while one.

a. As far as you know, with respect to their availability, performance, and cost, do you believe that plastics could be more extensively employed than they now are in building?

b. If so, what specific plastics and with what specific advantages? If not, because of what disadvantages?

c. Can you indicate possible sources of further information?

d. If such material is available, would you please send me the results of any work you have done in this connection.

Any supplementary remarks will prove helpful, I am sure. Thank you.

The following list of representative suppliers, molders, and fabricators from whom information was requested at the beginning of this study was compiled with the help of Professor Albert G. H. Dietz of the Department of Building Engineering and Construction, MIT.

APPENDIX C (continued)

Mr. Charles Romieux, American Cyanamid Co., Plastics and Resins Div.,
30 Rockefeller Plaza, New York 20, New York

Mr. Edward Cooper, Experimental Station, E. I. DuPont de Nemours,
Wilmington, Delaware

Dr. D. S. Frederick, Rohm & Haas Co., Design Laboratory, P. O. Box
219, Bristol, Pa.

Mr. H. F. Wakefield, Development Dept., Bakelite Corp., 30 E. 42nd St.,
New York 17, New York

Mr. W. C. Goggin, Plastics Technical Service, Dow Chemical Co., Midland, Michigan

Mr. M. Reynolds, Marco Chemicals, Inc., Elizabeth Ave. W., Linden, N.J.

Mr. W. P. Moeller, Plastics Div., Celanese Corp. of America, 290 Ferry
St., Newark 5, N.J.

Dr. L. W. A. Myer, Tennessee Eastman Co., Kingsport, Tennessee

Mr. George A. Fowles, B. F. Goodrich Chemical Co., 324 Rose Bldg.,
Cleveland 15, Ohio

Dr. D. L. Schoene, U. S. Rubber Co., Naugatuck, Conn.

Mr. R. G. Nelb, Vibrin Development, Naugatuck Chemical, Naugatuck, Conn.

Plastics Division, Hollingshead Corp., Camden, N.J.

Mr. Wyman Goss, Plastics Div., General Electric, 1 Plastics Ave., Pittsfield, Mass.

Mr. George Clark, Formica Co., Cincinnati, Ohio

Mr. Paul Leverett, Park-Wood Corp., Wakefield, Mass.

Mr. A. W. Russell, Russell Reinforced Plastics Corp., 37 W. John St.,
Hicksville, Long Island, New York

Dr. Harold Mohrman, Plastics Div., Monsanto Chemical Co., Springfield 2,
Mass.

Mr. John Moore, Prolon Sales Div., Pro-phy-lac-tic Brush Co., Florence,
Mass.

APPENDIX C (continued)

Mr. Milton Brucker, Pres., Zenith Plastics, Depot MP-2, Gardena,
California

Progressive Industries, Inc., Long Island City, New York

Atlas Mineral Products, 8 Ash St., Mertztown, Pa.

Mr. C. Bacon, Plaskon Div., Libby-Owens-Ford Glass Co., 2112 Sylvan
Ave., Toledo 6, Ohio

Selectron, Pittsburgh Plate Glass Co., 5th at Bellafield, Pittsburgh 13,
Pa.

Mr. Langdon P. Williams, Director of Pub. Relations, Society of Plastics
Industries, 67 W. 44th St., New York 36, New York

Eighteen replies were received, and with no exception all of them were encouraging; most of them offered further cooperation, and many of them were definitely enthusiastic. Specific points of information contained in various letters have been incorporated in the body of this report.