

CHEMICAL RIGIDIZATION OF PREFORMED FLEXIBLE FOAMS

J. F. HANNY, J. W. JONES, G. H. PETERS, AND J. C. SCOTT

CAPSULAR RESEARCH AND PRODUCT DEVELOPMENT DEPARTMENT

THE NATIONAL CASH REGISTER COMPANY

In order for man to continue to expand his knowledge of space, it is essential that he develop materials and structural concept that can be used to erect, support, and maintain large space laboratories. The materials and structural designs selected must be compatible with the payload capabilities of current launch vehicles.

At the present time, there are definite weight and volume limitations imposed on the space structure designer if he only considers the conventional stay-as-they-are structures. However, if he can extend his material reservoir to include expandable structures, his design goals can be achieved without sacrificing valuable space or equipment.

The Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio, has recently awarded NCR a research and development contract to develop and optimize a chemical rigidization system for expandable structures. The NCR chemical rigidization system utilizes a pre-formed, flexible polyurethane foam, of a high porosity grade, as a matrix phase for a vinyl-type monomer. The impregnated foam system is then adhered to the surface of the expandable structure. When desired, the structure may be expanded, and an on-command polymerization of the monomer is initiated, thereby producing a rigid structure.

The anticipated application for this rigidization system dictates a set of rigorous conditions, under which it must operate, as well as a number of design requirements that must be met. The system must be stable in an aerospace environment, as well as under terrestrial conditions. However, when exposed to

an aerospace environment, the rigidization reaction must be amenable to a low energy initiation mechanism, and once initiated, it must be fast and effective. The rigidized material should possess a high strength-to-weight ratio and a low density.

With these conditions and requirements in mind, NCR remains confident that this rigidization system is quite adaptable to its anticipated application.

The rigidization of the flexible foam is primarily dependent upon the polymerization of the absorbed monomer. The vinyl-type monomer is a clear liquid, having the following physical properties:

Boiling Point	-	200° C at 1 Torr
Color	-	Colorless to pale amber
Specific Gravity	-	1.076
Refractive Index	-	1.4620
Water Solubility	-	Insoluble

The polymer is obtained by a free radical polymerization mechanism and is a clear, glass-like, completely thermoset material. Some of the polymer's physical properties are as follows:

Tensile Strength at 25° C.	-	4000 PSI
Refractive Index	-	1.5024
Dielectric Constant (60 CPS)	-	5.5
Thermal Conductivity - (BTU/hr., 1 ft. ² /°F/in)	-	2.4
Light Transmission (% at 4500 Å)	-	92

To effect polymerization of the monomer, it is necessary to dissolve therein a free radical generator or initiator. The decomposition of this initiator into free

radicals is hastened by the presence of a reducing agent. Studies indicate the initiator has a slight tendency to decompose when dissolved in the monomer, and permitted to stand at room temperature. If the solution is allowed to stand long enough, the free radical concentration may increase to a critical level, thereby initiating polymerization. It is this gradual build up of polymer chains that limits the stability of the system. However, by introducing into the system some free-radical scavenger or polymerization inhibitor, these free radicals are "tied up" and rendered inactive. During the course of this study, it was observed that oxygen is a very effective inhibitor for this system, and that exposing the impregnated foam to atmospheric oxygen gave a shelf life in excess of six (6) months. Permitting the impregnated foam to stand for this length of time had no adverse effects on its normal rigidization characteristics.

Rigidization Rate

The rate at which the flexible foam can be rigidized is dependent upon: (1) the polymerization rate; (2) the number of initiation sites and; (3) the impregnated foam's density. The effect of monomer concentration on the flexible foam rigidization rate has been determined by maintaining a constant polymerization rate and number of initiation sites, and altering the concentration of monomer in the impregnated foam.

The samples were prepared by impregnating the flexible foam matrix with various amounts of monomer initiator solution to obtain different rigidized foam densities. The polymerization reaction was initiated by introducing a catalyst into the monomer-impregnated foam. This was accomplished by adhering NCR microcapsules containing the catalyst to the surface of a nichrome heater strip and bringing this into contact with the foam surface. Initiation was achieved by passing an

electrical current through the heater strip.

Figure 1, is a graph of the rigidization time versus density of the rigidized foam, and indicates the range of monomer concentration that can be used without appreciably changing the time required to rigidize a given volume of flexible foam. This indicates that foam impregnation is not a very critical area, unless the strength properties of the rigidized structure are affected. (All foam sections had the same initial volume (5" x 5" x 1") and were rigidized at 0.05 Torr.)

Rigidization Exotherm

The rigidization exotherm is the result of heat energy being generated by the rapid bond formations in the free radical polymerization of the monomeric foam impregnant. The maximum exotherm obtained from the rigidization process is a function of the quantity of foam impregnant. The greater the quantity, the higher the exotherm.

Studies were conducted to determine the relationship between rigidization exotherm and the density of the impregnated foam. Samples of impregnated foam were prepared having densities in the range of 4.8 lbs/cu. ft. to 31.5 lbs/cu. ft. A thermocouple was inserted into the sample, and the assembly placed in a vacuum chamber. After the pressure was reduced to 0.075 Torr, the rigidization was initiated by releasing the encapsulated polymerization catalyst. The peak temperature was observed and recorded as the rigidization exotherm. Figure 2, is a graph of the rigidization exotherm versus the density of the impregnated foam. By varying the density of the impregnated foam from 2.5 gms/in³ to 5.0 gms/in³, the rigidization exotherm is increased by approximately 60°F.

Strength of Rigidized Foam

Previous studies indicated the overall rate of rigidization and the rigidization

exotherm are dependent upon the density of the monomer-impregnated, flexible foam. The following study was initiated to determine the effect of the varying of the density of the impregnated foam on the strength properties of the rigidized foam. The samples rigidized during the exotherm study were used to determine the tensile and compressive strengths. One-inch cube sections were cut from the rigid samples and adhered to specially-designed, stainless steel fixtures for tensile strength evaluation. Figure 3, is a graph of the tensile and compressive strengths of the rigidized foam as a function of the density of the impregnated foam.

Composite Adhesive

NCR's expandable and rigidizable solar collectors are based on a structural composite, made up of aluminized Mylar and flexible foam. The composites' structural integrity and packaging capability is dependent upon the development and/or selection of flexible adhesives that will effectively adhere to the composite materials.

A number of adhesives of various types are being investigated:

- 1) Silicones
- 2) Urethanes
- 3) Polyesters
- 4) Polyamides
- 5) Polysulfides
- 6) Epoxies
- 7) And combinations thereof.

Some of the properties and requirements that must be inherent in the adhesive systems are listed below:

- 1) Good adhesion to the Mylar and the impregnated foam before and after rigidization.

- 2) Flexibility upon curing
- 3) Minimum shrinkage upon curing
- 4) Good flexural strength
- 5) No adverse effects on composite materials or the rigidizing system.
- 6) Adaptability to space environments, as well as terrestrial environments without adverse effects on the system, and
- 7) Adaptable to various methods of application - casting, spraying, etc.

The most promising adhesives evaluated to date are the silicones and polyurethanes. Many of the adhesives being investigated will bond to Mylar and the dry foam, but when the monomer is introduced into the foam, a delamination occurs at the Mylar interface. It is most desirable to obtain an adhesive that will bond to both the Mylar and impregnated flexible foam, thus allowing the foam to be impregnated before the solar collector is assembled. By impregnating the foam first, it is possible to obtain a more uniform distribution of the monomer in the foam.

A second problem area related to the adhesive system is the quality of the reflective surface. The reflective surface of most of the collectors has been good, but there is need for improvement. There appears to be a correlation between the quality of the reflective surface and the composite adhesive. It is anticipated that once a functional adhesive is developed and/or selected that meets the bonding requisites, the problem of obtaining excellent mirror surfaces will also be solved.

Rigidization of Solar Collectors

A number of fifteen (15) and eighteen (18)-inch diameter solar collectors have been rigidized under vacuum conditions, 10^{-3} Torr. These preliminary experiments were designed to evaluate the rigidization system's functionality, reproducibility,

triggering mechanism, and the geometric tolerances that could be maintained during rigidization. To date, the rigidization system has functioned very effectively and reproducibly, giving consistent structural properties, rigidizates, and geometric tolerances. The collectors also possessed very good reflective surfaces.

Figures 4 and 5, are cross-sectional diagrams of the fabricated collectors, and Figures 6 and 7, are photographs of the eighteen (18)-inch and three (3)-foot diameter solar collectors that were rigidized in the high vacuum facilities at Wright-Patterson AFB.

Additional collectors, ten (10) feet in diameter, will be fabricated, rigidized, and evaluated in the near future to determine the scaling effects induced by the presently used materials and fabrication techniques.

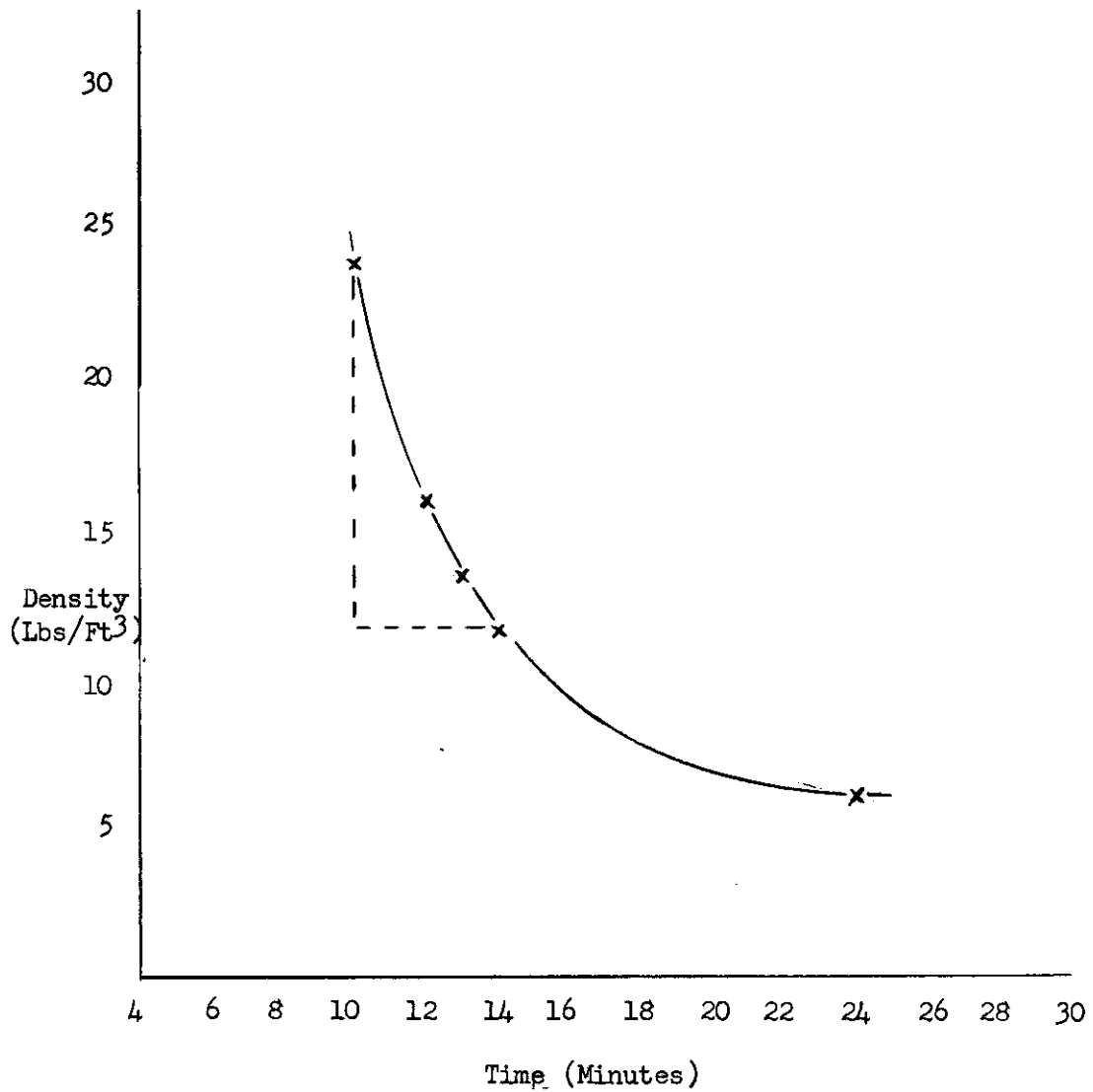


FIGURE 1
Rigidization Rate Vs. Density
of Impregnated Foam

Contrails

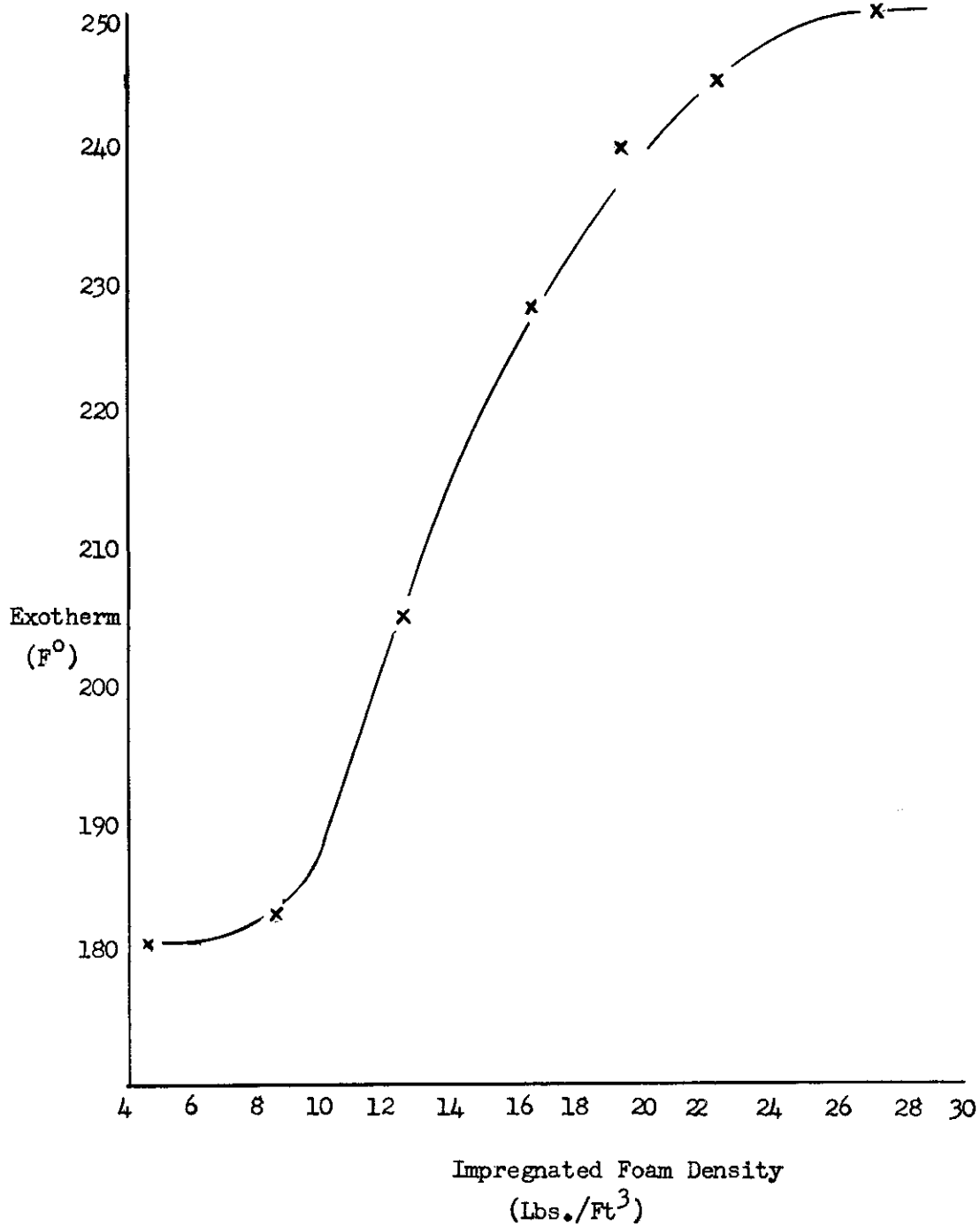


FIGURE 2
Rigidization Exotherm Versus
Impregnated Foam Density

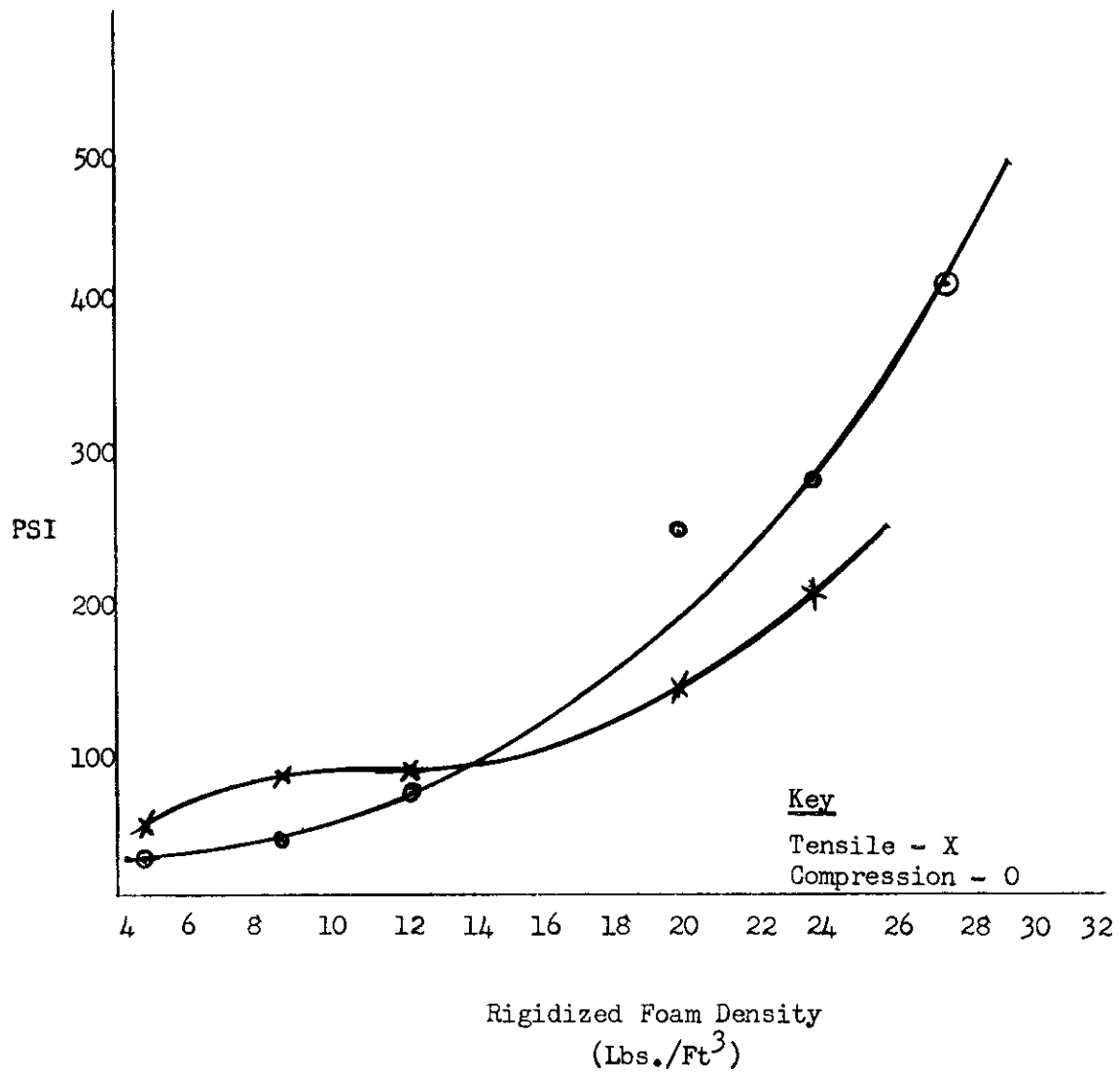
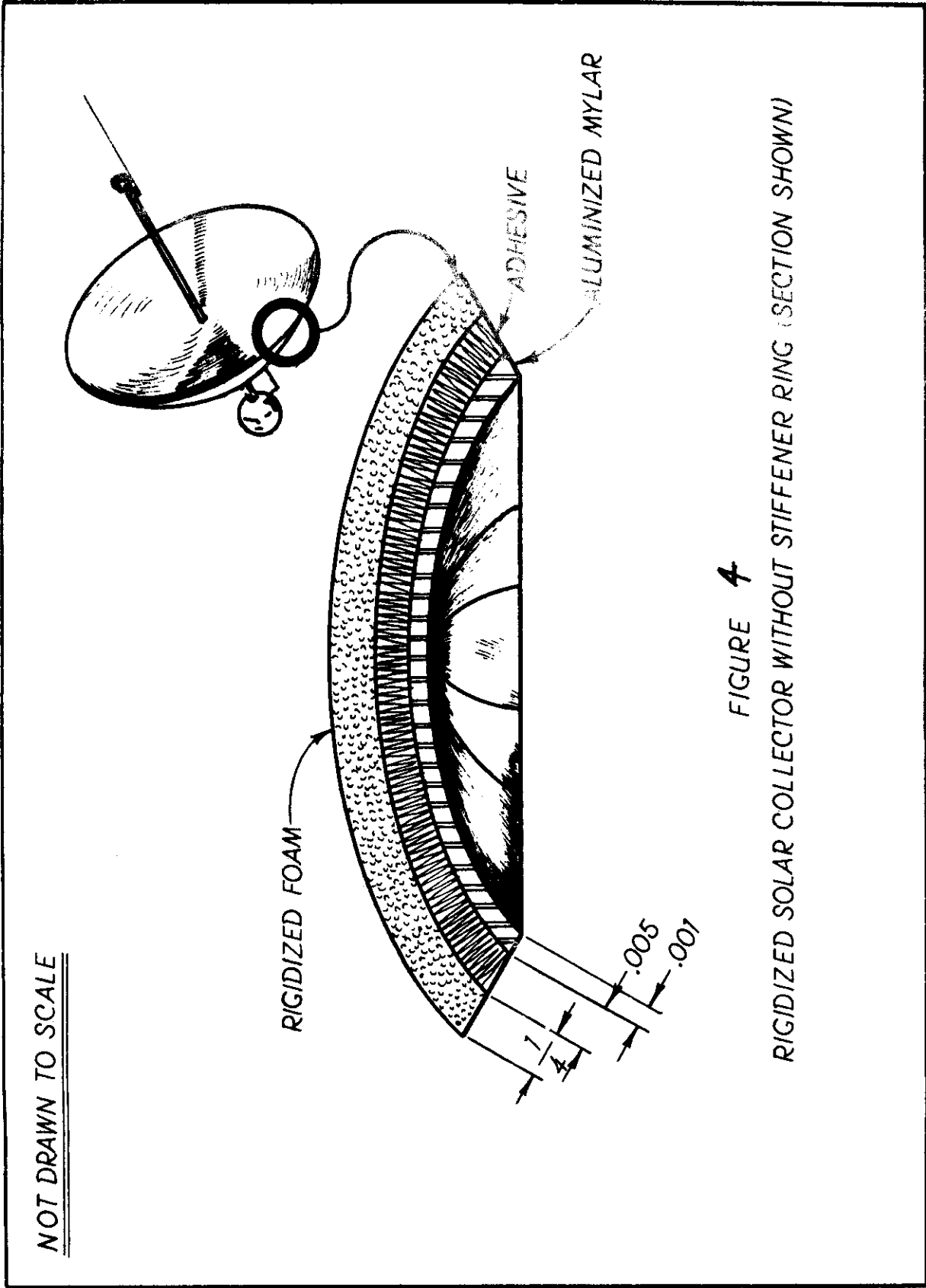
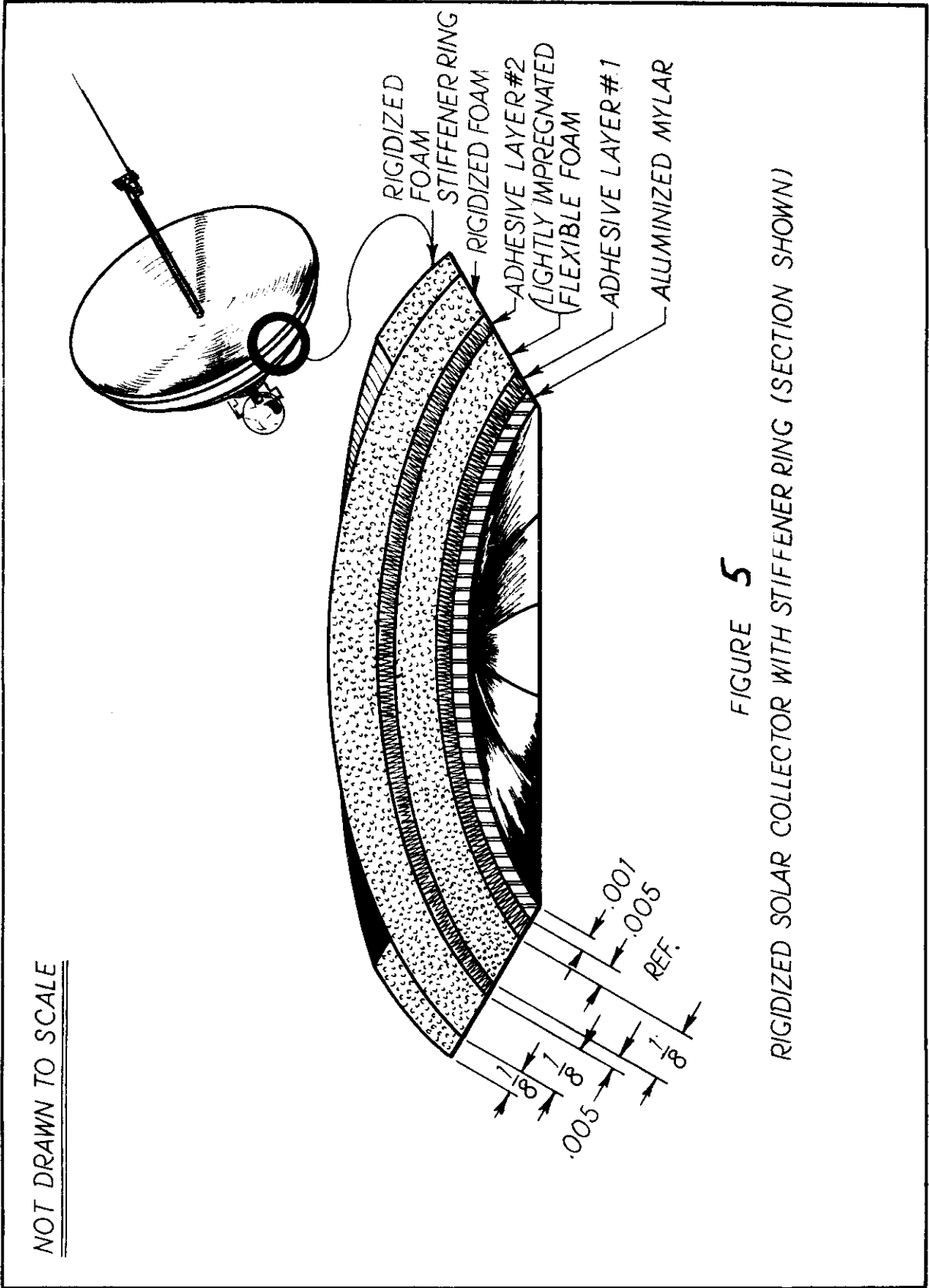


FIGURE 3

Strength Properties of Rigidized
Foam Vs. Rigidized Foam Density





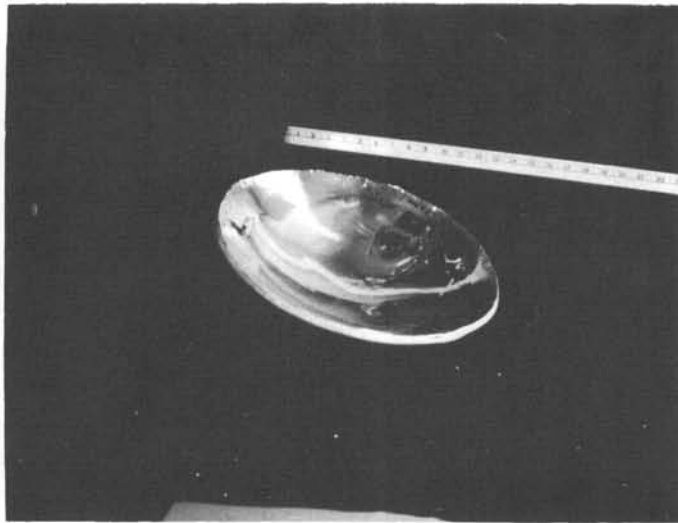
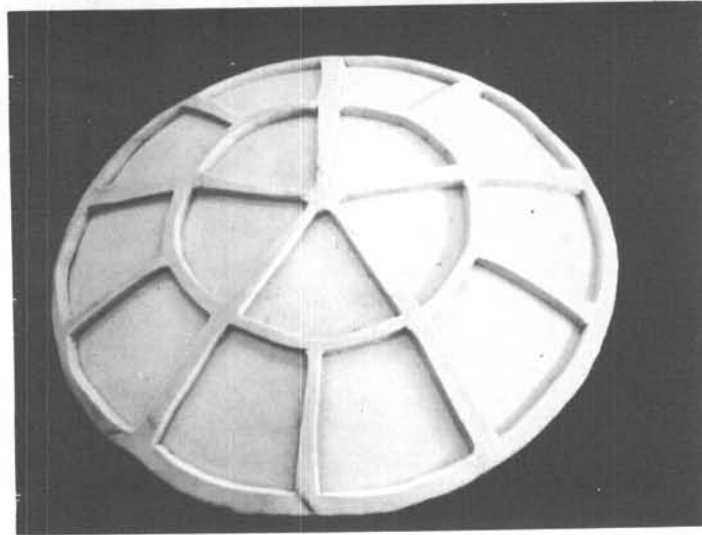
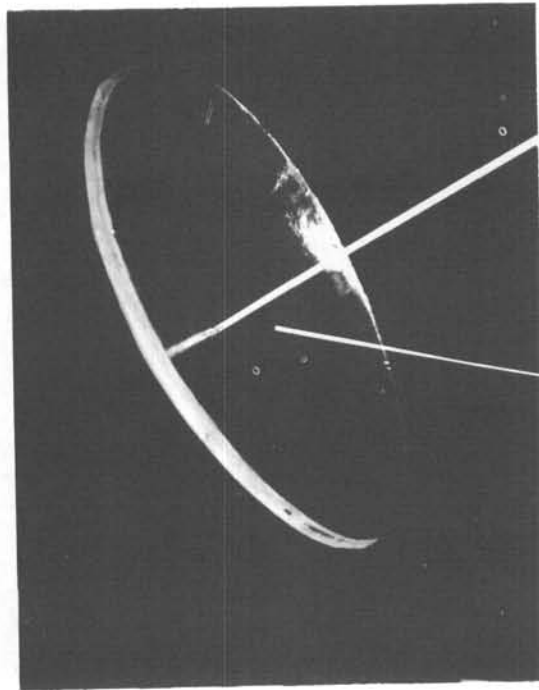


FIGURE 6
Rigidized $1\frac{1}{2}$ Foot Diameter
Solar Collectors



BACK



FRONT

FIGURE 7

Rigidized 3 Foot Diameter Solar Collector