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FINAL REPORT

Fabrication of Four Focusing Solar Collector Segments of Widely Differing Geometries From Fiber-Reinforced Polymer Honeycomb Composite Panels

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Abstract

Focusing solar reflector support panels were fabricated from fiber-reinforced polymer honeycomb structural sections using four different geometries. These panels and geometries were:

1) 2@ 20" x 24" spherically contoured facet with 10-meter focal length

2) 1@ 10° parabolic gore segment with 364" focal length

3) 1@ 3-meter diameter parabolic contour circular facet

4) 1@ 4' x 16' spherically contoured rectangular facet with 1000' focal length

Molds were prepared for each of the reflectors to the required contour and geometry. The master molds were prepared from plaster of Paris or from low profile tooling resins. Details of the mold construction are provided in this report. All materials used are described and details of the processes involved are described. All molds remain in storage at KSCI's Russell, KS facility.

Executive Summary and Conclusions

This project resulted in the preparation of four different molds for the fabrication of fiber-reinforced polymer honeycomb structural panels to support focusing solar collector reflectors in specific geometric profiles. The fabrication of these four panels was successfully completed and they were delivered to Sandia National Laboratories for testing.

While the optical test results are not yet available for diagnosis, the advantages of FRPH panels for the intended purpose appears to be significant. The light weight, high strength, resistance to environmental deterioration, and low cost of FRPH implies that these panels may be superior to those manufactured from alternative materials.

Cost, being the overriding factor once acceptable performance is obtained, can be estimated from design considerations and materials usage. With respect to economics, the larger the panel the lower the cost per area at least for sizes that can be transported by truck or rail. The ratio of edge length to surface area determines the production costs to a great degree.

If molds are prepared and ready for production, small prototype quantities (1-3 panels) can be produced for between $4 and $7 per pound. For semi-production quantities (10-25 parts), the price drops to between $2.50 and $3.00. In mass production of large pieces, costs would be between $1.50 and $2.00 per pound. Small area panels

Table 0.1
Estimated Panel Cost per Square Foot

Cost ($/lb)	Weight (psf)		
	1.00	1.75	2.75
$5.00	$5.00	$8.75	$13.75
$2.75	$2.75	$4.81	$7.56
$1.75	$1.75	$3.06	$4.81

of 2-inch thickness would weigh in the neighborhood of 1.0psf. Medium size panels with 4-inch core would weigh approximately 1.75psf. Large panels with 6-inch core would weigh approximately 2.5psf. These weights translate into the costs per pound given in the Table 0.1.

In this investigation, the most difficult problems were encountered in mold preparation. Two different materials were used to form the base for the molds, each having advantages and disadvantages. The materials were plaster of Paris (hemi-hydrated gypsum) and polymer concrete, where a screened inorganic aggregate is bonded with a polymer resin rather than Portland cement.

One of the most important characteristics of a mold material to be used for panels having high accuracy profiles is zero shrinkage during the forming process. Plaster of Paris is clearly a superior material in regards to shrinkage, but other characteristics tend to make it less desirable, particularly for the preparation of large molds. Gypsum's high density, rapid set time, slow drying time, softness, and brittleness all combine to make this a difficult material to use in large volumes or where multiple applications are necessary. It is estimated that a plaster of Paris mold would provide a working life of 5-10 panels. Since mold preparation during this prototype study was both time consuming and therefore costly, this small number of production parts would greatly increase per unit costs even if the plaster mold were used as a master for more durable FRP production molds.

Polymer concrete molds exhibit higher shrinkage, but after curing provide a stable base that can be built up to the desired profile with successive applications of highly thixotropic resins. The surfaces are stronger and more resistant to wear and tear. They are also easier to repair. The number of production panels that could be produced from this type of mold is estimated to be between 50 and 150 parts with little repair expense.

Resins with inorganic fillers of both powder and fiber are remarkably flexible, Thus molds of great size can be prepared and used and even transported with a low degree of anxiety. If required, profile changes due to shrinkage can be tuned out by building a flexible mold support frame that can be adjusted to the desired geometry. This method could also, in principle, be applied to large, flat panels in the field to compensate for installation variations.

Plaster molds may be of more use for small scale reflector panels having short focal lengths. For these, however, FRP molds may be less expensive in the long term for large production runs. For large scale panels, FRP and FRPH molds appear to be superior in terms of cost. Performance advantages will not be know until the completion of optical testing.

Section 1.0
Introduction

1.1 General Solar Concentrator Reflector Support Panel Requirements

Solar concentrator reflector assemblies typically consist of three major subassemblies. These are: 1) the basic overall support structural frame, usually metal, 2) the reflector support panels, and 3) the reflector surfaces per se. In the case of sun tracking units, drive motors and control systems are added to keep the sun's image focused on a boiler assembly.

Since the reflector consists of large areas for even small electric power outputs, the overall cost of a focusing solar electric system is driven in large measure by the cost of the reflectors and the panels that provide their geometry and transfer mechanical stresses induced by wind, gravity, and acceleration to the overall structural frame. Since gravity plays an important role in the design of the structural frame, the weight of the reflector surfaces, and the reflector support panels, significantly influences overall structural design weight and cost.

While there are several reflector surface concepts, the present study is limited by design to those panels used to support glass reflector surfaces as a primary objective, but it is important to note that several other optical surface materials may be used in place of glass. Glass has been chosen by many solar power developers for use as a reflector surface primarily because of a combination of efficiency of solar reflection and its long life. However, glass is heavy and can not be used as a self-supporting reflector but must be applied as a thin layer to a supporting panel of materials that possess greater strength-to-weight ratios.

The purpose of this investigation is to study the effectiveness, optical efficiency, robustness, practically, utility, and determine an overall cost yardstick by producing a series of widely varying types and sizes of solar concentrators from fiber reinforced polymer honeycomb (FRPH) sandwich panels for the purpose of supporting bonded glass reflector surfaces.

The focus of this study will be on the manufacturing methods and process that hold promise for meeting all the technical requirements and, especially, the cost constraints of focusing solar collectors from FRPH panels.

1.2 Why Fiber Reinforced Polymer Honeycomb Structures

1.2.1 Overview

The rational for investigating the fabrication of focusing solar collector support panels using FRP is based upon three basic considerations. First, the general properties of fiber-reinforced polymers. Second, the strength to weight advantages of honeycomb sandwich structures. Three, the potential low cost of FRPH when specific items are produced in large quantities. Each of these three advantages will be explained in some detail to set the stage for understanding the purpose of this initial fabrication study.

The following is a partial listing of the relevant characteristics of chemically reactive thermoset resins reinforced with fibers and formed into honeycomb panels for use as focusing solar collectors.

- *Low cost
- *High strength to weight ratio
- *Design versatility
- *Broad selection of polymers available
- Resistance to natural and corrosive environments
- Durability and toughness
- Vibration dampening
- Low thermal conductivity/diffusivity

The four items designated with asterisks will be discussed in greater detail.

1.2.2 Low Cost

On a per pound basis, fiberglass reinforced thermosetting polymer materials, prior to forming, cost $0.85 to $1.35 per pound. In comparison to steel, steel reinforced concrete, and most other structural materials, which sell for $0.10 to $0.20 per pound, basic FRP materials are not cheap. However, there are significant compensatory considerations. The proper utilization of FRP in the form of structural sandwich panels produced in quantity by mechanized production methods are much lighter in weight and the completed supporting structure requires less material and assembly as compared to other structural materials. It is not unusual for a moderately loaded FRPH structure to be equally strong as a steel structure, even though, if subject to large temporary loads, it may suffer a greater deflection for short periods and may weight as little as one tenth that of the comparable steel structure. Further, the lighter weights of FRPH make them much easier to erect and assemble. Field erection costs can be as much as one third to a fifth the cost of equivalent steel structures. Shipping costs are less and since FRPH structures last longer, require minimal maintenance. Overall costs of FRPH can be cheaper both initially and over their life cycle. The cost of tooling for FRPH curved structural panels is also less expensive than for large steel panels formed by stamping or explosive forming.

Fabrication costs of FRPH on a prototype basis, neglecting mold costs, are currently $3.00 down to $2.50 per pound depending upon panel size, special attachments, close-outs, hard points, and, of course, volume. KSCI's four year goal is to reduce this cost to $1.50 to $2.00 per pound for larger panels of moderate weight (3-6 pounds per square foot) and down to $1.25 to $1.50 for heavier panels. Given the lower weight and cost of the supporting structure, and the more rapid and less costly erection time, FRPH panels appear to be substantially cheaper than conventional materials overall. As compared to prototype production, mold costs will be low when amortized over a production run and would not add more than a few cents per pound of material to overall cost.

1.2.3 Strength-to-Weight Ratio

Making general comparisons of materials whose strength and stiffness properties are as different as those of steel and FRP composites are is not a simple matter. Steel has a typical elastic modulus of $30x10^6$psi and its design strength is 60,000 psi whereas FRP has a modulus in the range of 2.0 to $4.0x10^6$psi and an ultimate strength of 30,000 to 35,000 psi.

Furthermore, polymers suffer significant inelastic deformation (creep) when subject to continuous loads which impose unit stresses above 5,000 to 6,000 pounds. Also, if the structure composed of FRP is subject to alternate loading and unloading above 3,000 to 3,500 psi cyclic fatigue can lead to failure.

Another important criteria is whether the design is determined by strength or deflection criteria. Diving boards are designed to provide adequate strength and large deflections under load, while bridges need great stiffness in order to reassure the user as to its apparent safety and reliability. Other structures require a certain reliable strength plus an adequate safety factor, but design loading occurs only infrequently and sizable deflections can be allowed.

Based upon these three broad design categories, the weight of FRPH and steel structures can be compared. However, the shape factors must also be considered. Steel, due to its high modulus of elasticity, can be formed into I-beams that distribute the steel in areas of greatest local stresses. While FRP can also be formed in a similar shape, the lower modulus requires that the stress transfer web be much thicker than steel. FRP composites have been produced to mimic structural steel I-beam geometries, but tests quickly disclosed the shortcomings of this approach. Failure occurred at the web-to-flange intersection due to high local stresses exacerbated by web buckling. Webs can be made thicker, or dual webs can be fabricated, or dual webs with horizontal cross ties. If this process is taken to its logical conclusion, the result is essentially a honeycomb sandwich structure. Cardboard, i.e. corrugated paper honeycomb was developed because paper, like FRP, is a low modulus material. A properly and optimally designed honeycomb possesses the greatest strength to weight of any geometry for a low modulus material because local buckling forces are shared and contained by multiple webs.

For FRPH panels under deflection-based design criteria, such as those for a bridge or bridge deck, the weight of FRPH is one fifth to one seventh that of steel. In the case of a strength-based design, the weight ratio of FRPH to steel may be one tenth to one twelfth. For structures such as solar collectors, which require adequate strength to resist occasional high winds and wind gust for short periods, substantial deflections may be allowable, as long as adequate safety factors are maintained. For these applications, a focusing collector reflector support panel would weigh approximately one tenth that of steel and would be a tough, damage-resistant panel. It is assumed that no deflections would be sufficient to break the thin glass reflecting surfaces.

The geometry of honeycomb structures is ideal for stiffness, that is, resistance to deflection. The load bearing layers of a panel must resist compression in the top surface and tension in the bottom surface. The greater the geometric separation, the greater the resistance to deflection. In fact, the resistance to deflection is a square term with respect to the separation of these layers. Thus, doubling the core of a panel of otherwise similar characteristics results in a four-fold increase in the stiffness. The core must resist local applied loads on the top surface and in-plane shear and must be designed to accommodate these forces. In general, core structures weight approximately 10% of the weight of an equivalent thickness of solid FRP. Even though FRP possess a low modulus, the sandwich geometry reduces the overall weight.

1.2.4 Resistance to Ambient Environmental Factors

The misuse of plastics in many outdoor exposures and their rapid failure has created considerable concern as to the useful life of structural FRP as an engineering material. A prime example of these failures was the use of thin plastic sheets glued to the tops of several hundred billion dollars worth of automobiles as a top surface decoration and the use of unsuitable and UV-sensitive plastics for patio covers which frequently fail in three to five years in areas of high solar exposure. Also, the cracking, checking, and fiber bloom which occurred on boats without adequate UV-resistant paints or gel coats.

These failure mechanisms have long been understood and with proper materials selection, preparation, and protection these problems are avoidable.

Properly engineered FRP boats have been exposed to wind and water (including salt water) for nearly forty years with minimal maintenance. No material is perfect, and each has its limitations, but material specialists have solved or mitigated these problems. The polymer industry continues to produce new materials possessing greatly improved properties when compared to those used forty or even ten years ago.

For applications such as focusing solar collectors, the structural panels will rarely see full-time, long-term direct solar exposure due to the reflective (and therefore protective) working surface. Thus, by using pigments and protective coatings, structural panels of FRP can be expected to have useful lives of 50 to 75 years or longer with minimal maintenance.

1.2.5 Design Versatility

Using FRPH, every aspect of the panel design can be easily and rapidly varied. The thickness of all sections in a honeycomb panel can be changed without greatly affecting production. Panels can be insulated by filling the honeycomb core with closed-cell foam. If temperature-induced deflections change the focal length, compensating layers can be added to the back surfaces. Holes in the structure can be repaired. If a selected panel design is found to suffer too large a deflection, additional laminae can be placed on the back surface to increase stiffness and save the cost of constructing completely new panels. A variety of edge treatments, close-outs, hard points, and connections can be provided. Instrumental sensors are easily embedded in the panel at almost any location since high temperatures are not required during fabrication. Any color can be used for aesthetic purposes or panel coding. This list is not complete, and does not address the constituent material variations or geometry options discussed in the following sections, but does provide an overview of design variability.

1.3 Types of Materials Available for FRPH Production

The purpose of this section is to provide a brief and narrow overview of the various generic types of polymers and fibers that appear currently most suitable for focusing solar collector reflector support panels.

1.3.1 Polymers.

There are two types of polymers that are relatively inexpensive and possess general properties for use as support panels. These are: polyester and vinyl esters. Epoxies can also be considered but these are 20-50% more expensive on a weight basis. Both polyesters and vinyl esters are produced commercially by several firms in hundreds of different variations possessing a myriad of properties. Over time, these materials can be carefully tailored to specific applications. The various producing firms have effective and efficient technical support teams that provide rapid and reliable polymer selection recommendations. KSCI has used this wealth of technical information for a number of projects, including this one.

1.3.2 Reinforcing Fibers

While reinforcing fibers can be made from glass, high-strength synthetics, or carbon, the cost for the higher strength fibers is greater than the improvements in composite material properties for most non-aerospace applications. Therefore, for almost all commercial uses, glass fibers are the fibers of choice.

Fibers are available as multi-strand roving, chopped strand mat, uniaxial stitched fabric, and a wide variety of woven materials. This wide selection of fiber types permits fibers to be used efficiently by placing them in the optimum orientation to accommodate the strength requirements of the structure.

1.3.3 Additives

Additives consist of three types: catalysts, promoters, and other materials. The first two are used to control the rate and extent of cross-linking. Additional additives, such as calcium carbonate, are used as fillers to reduce polymer costs but will increase weight because of higher density. Selection of additives is usually based, in part, on prior experience.

1.4 Types of Honeycomb Cores.

1.4.1 Technical History

Almost one hundred years ago, inventors discovered that paper (a low- modulus cellulose material) could be used as a temporary, low-duty structural material by forming honeycomb sandwich structural sheets. The cardboard industry was developed around a simple concept - the fabrication of panels at high speeds by gluing together alternating layers of flat and corrugated sheets. A water-based glue was applied to the tops of the corrugated materials and flat sheets were brought into contact to form a single corrugated layer between two flat facing sheets. Alternatively, multiple sheets of alternating flat and sinusoidally corrugated layers can be assembled to build a desired thickness. Thus, a new, light-weight structural material arrived. On a weight basis, cardboard remains the most widely used honeycomb sandwich structural system and possesses an amazing strength, so long as it is dry or water proofed.

Only a short innovation step was required to substitute FRP for paper. A increase in cell size could be utilized because the greater strength of FRP did not require small cells to generate adequate core mechanical properties. The forming of both flat sheets and corrugated layers by contact molding was an old art which has been in the public technical domain for many years. The Kunz methods are well know as over 200 examples for various uses have been produced and widely publicized. The apparatus for producing FRP core materials for honeycomb panels and paneling were set forth in US Patents 3,912,573 and 4,049,487. These patents, issued in 1975 and 1977, are now expired. A more recent patent for the production of an open-cell FRP core is covered by US Patent

5,047,277 issued on September 10, 1992. This patent is currently in effect. For the purposes of this development, the patent holder gave permission to use this patent for experimental purposes. All other aspects of FRPH technology known to the authors are public knowledge and well known.

Figure 1 shows the cross-section of what is described as the standard core configuration. When used in structural panels, the cross-section shown is placed with the cell axis normal to the facing planes. In this respect, FRPH differs from typical cardboard which has cell axes parallel to the faces of the panel.

Figure 2 illustrates essentially the same geometry but without flat webs and with the corrugated layers indexed with the peaks touching. This geometry is less strong and possesses a lower effective panel modulus than standard core but it also uses less material and possesses aesthetic advantages for translucent panels. Also, if the indexed corrugated layers are combined with flat webs, the result is essentially a re-indexed standard core geometry.

Figure 3 is the 'nested wave' core produced under patent 5,047,277. This type of core has several advantages. It is much simpler to produce cylindrical objects such as pipes or tanks or complex compound curves due to the ability of unrestrained corrugated core to flex since the core sheets are held together by adhesive bonding of the corrugated crowns to light gauge stringers.

The cross-sectional (web) thickness of both the flat and corrugated layers can be independently produced in thickness of 0.025 inches to 0.250 inches, or greater, as required. The production of cores possessing different web thickness allows the control of strength, modulus, and directional load sharing.

Honeycomb core panels can be produced in a wide range of sizes. Current production equipment permits core heights of up to 40 inches, though the greatest core produced to date has been 20.5 inches. In the production of very large objects, the core is assembled into smaller pieces called logs that can be more conveniently handled. These are placed into the panel assembly and glued in place by adding logs to other logs until the required dimensions are obtained.

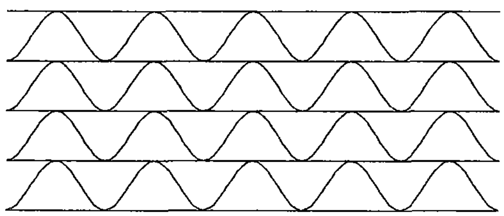


Figure 1 - Schematic of 'standard' Honeycomb Core

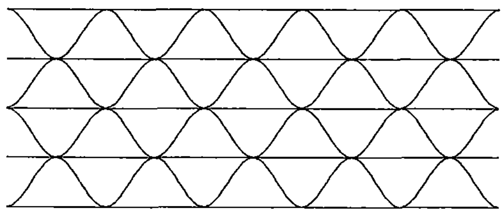


Figure 2 - Schematic of 'closed-cell' Core with Peak-to-Peak Indexing

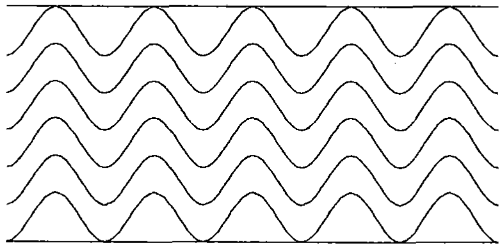


Figure 3 - Scematic of a 'nested-wave' or 'open-cell' Core Configuration

1.5 Panel Surface Selection

1.5.1 Overview.

Another advantage of honeycomb structures is the versatility of design that arises from the fact that panel faces can be produced from polymers that are different, in part or in whole, in composition and fiber placement than those used to produce the core structure. In addition, there are two different methods for bonding the core to the faces.

If the structure is not too large, one or both surface panels can be wet-bonded to the core. The core, which has been previously fabricated, can be placed upon the uncured face panel laminate creating a wet bond. After the first panel surface is cured with the core attached, a second panel surface is prepared with saturated fibers according to the specifications. The first panel and attached core are inverted and set on the second panel surface producing a panel that is wet bonded on both surfaces of the core.

The second fabrication method is to produce the panel surfaces using pressurized laminate production methods. The advantage of this approach is that prefabricated panel surfaces can be stockpiled and then cut to the required size. Also, pressed FRP sheets have a modulus of elasticity of 4.0×10^6psi whereas a hand-laid laminate has a modulus of 2.5×10^6psi. This 1.5×10^6psi gain is a 60% increase and the overall amount of material in the panel surface can be reduced accordingly providing a significant cost savings.

The only problem with this method is the requirement that the core be strongly bonded to the top face. If the panel is placed horizontally and loaded on the upper surface, the top face will be placed in compression and will be prone to buckling. This face will eventually de-bond from the honeycomb core at the bond line due to combined buckling and shear stresses. This failure starts slowly but, since the critical buckling stress decreases as the inverse of the square of the radius of the de-bonded area, the localized area of failure grows exponentially and results in a sudden, almost explosive detachment of the top panel surface.

The bonding of prepared top panel surfaces is best accomplished by laying a polymer-saturated fiberglass mat over the panel surface and rolling it carefully to exclude all of the air bubbles. The core is then pushed down into the wet mat and forms what is in fact a wet adhesive bond. This bond strength, for all intents and purposes, is equal to that of an actual wet bond.

Lower faces need not be as strongly bonded to the core since, as loads are applied to the top of the panel, the core is forced down against the lower face and, as a result, it is rare for failure to occur at the lower core/face bond line so long as the panel is subjected to a positive bending moment.

1.5.2 Polymer Selection

Polymer selection for panel surfaces is based upon:

- The application
- The environmental exposure
- Panel surface requirements, frictional properties, wear needs, aesthetic concerns, and similar specifications as well as the usual physical properties.

1.6 Mold Materials Systems

1.6.1 Overview

There are several critical elements to be considered in selecting a materials system of the tooling for the molding of precision FRP parts. The strength of the mold must be adequate to survive the rigors of normal usage as FRP overlays in the wet state are laid on the surface and the air voids are rolled out by hand or machine. If molds are used for producing large numbers of pieces, strength becomes important. The design of the mold support system is also important, especially for weaker materials.

The fabrication of molds requires materials that possess rheological properties such that they will flow under light pressure to fill in small local voids and reduce high point but, once worked to a contour, remain fixed.

After a surface is formed to the desired configuration, the mold surface must harden from a semi-solid to a solid. During this transformation, shrinkage or expansion of even small linear dimensions can make large changes in the shape profiles. The profiles are of critical importance in all three dimensions for focusing collectors. Very few materials undergo drying or chemical setting reactions with low or ideally zero change in dimension. Shrinkage of materials can be overcome to some degree by placing a series of layers that are made thinner and thinner. Thus dimensional changes can be greatly reduced if the material bonds well to itself and is bonded to a stable base. This is not always the case.

The next and usually final step in preparing a tool for contact molding of FRP parts is to treat the surface with materials that prevent bonding of the FRP part being formed to the mold surface. Any adhesion of mold to parts will destroy the part or the mold or both.

For contact molding of large, high-precision parts of FRP for focusing solar collectors, there are currently two choices: plaster of Paris or a filled, chemically-reactive polymer resin, usually referred to as a tooling compound. Each of these mold materials has advantages and disadvantages that will be discussed briefly. Mold building is truly an art that is learned the hard way, mainly by making mistakes and developing the skills required to place and work semi-solid materials. Therefore, in most cases, the experience of the personnel involved may play the decisive role in selecting a materials system for preparing a mold where high precision of contour and surface finish is required as is needed for quality focusing solar collector reflector support panels.

1.6.2 Plaster of Paris (Gypsum Hemi-Hydrate)

For hundreds of years the ceramics industry has utilized plaster of Paris as a mold material. These materials have reached a high degree of development such that they are strong and possess essentially a zero coefficient of shrinkage/expansion during setting or curing transformations. They are easily worked and have adequate pot life and working times. Flow under pressure for placement and finishing is excellent. Plaster has made the transition from ceramics fabrication to the molding of low temperature liquid metals (i.e. toy lead alloy soldiers) to FRP contact molding.

There are two serious but well known difficulties that are to be avoided. First, wet plaster does not adhere or bond well to dry plaster. Thus, it is almost essential that the plaster mold be made in one pouring of the wet material. Even though plaster is relatively and adequately strong, thin lamina will separate and break up, destroying the mold.

The second undesirable characteristic of plaster is that for preparing smooth surfaces, excess water, more than required for the chemical reaction, is needed; therefore, the plaster mold must be carefully and completely dried prior to the finishing or placement of parting materials. This requirement also produces a thinner mixture that does not hold shapes well. For complete drying of plaster, particularly thick sections, a heat source is placed under the piece and air is blown over the top surface as water tends to migrate to the cooler areas. Drying tends to be a time consuming process whereas wetting of plaster is rapidly accomplished with low viscosity hydrophilic liquids.

Plaster of Paris is a useful material for the fabrication of molds for small pieces but large molds become heavy and an adequate supporting structure must be designed to prevent cracking of the mold. Surfaces of plaster are soluble in water and wetting/drying of water will cause alteration of the mold surfaces. The zero change in dimensions during curing is a very important advantage of this material. Focusing solar collector support panels of FRP can be made to high levels of perfection if careful workmanship is performed and the few shortcomings of plaster are observed.

1.6.3 Polymer Concrete

Polymer concrete, a mixture of thermoset resins and inorganic additives, are beginning to be used as molding materials. The high strengths and a larger degree of flexibility (strong tolerance to strain without fracture) as compared to plaster make this a superior molding system for many applications.

Resins possess the significant problem of large shrinkage relative to plaster and this can result in a change of profile for large pieces with curved surfaces. This is a serious problem for focusing geometric shapes. In the last five years, several resin producers are developing a series of low shrinkage materials, designated as low profile tooling resins. These resins are improving and linear shrinkages are being reduced, but remain larger than desired for high-precision profile work unless great care is taken in mold fabrication.

One off-setting advantages is that polymer concrete molds are sufficiently strong and flexible. For large, relatively flat pieces, a framework can be constructed that allows the controlled physical deflections of the finished mold to change the profile of the completed mold to bring it into conformity with the specified geometry. This is one method for fine tuning mold profiles.

A second method is to produce a mold and measure the profile or calculate the deflections expected for a given mold shrinkage and alter the profile such that the final profile is within specifications. Calculations alone are probably not adequate until supporting experimental data is available in sufficient detail and quantity to confirm the assumptions used in the analysis. Forming a series of molds to measure profile changes is time consuming and expensive but perhaps necessary, at least initially.

1.6.4 Surface Finishes

Preparing surface finishes is largely an art that depends upon skilled workers. Typically, a surface is coated to fill holes and sanded to remove projections. The process takes a keen observer and a steady hand. Also, the feel of the drag of the abrasive material is highly important to preparing a smooth surface without altering the overall profile.

After the desired finish and profile on the mold is obtained, it is necessary to treat the surface with a parting agent that prevents bonding of the FRP part to the mold surface. Various types of commercial preparations of soaps and silicones are available for this purpose.

Section 2.0
Project Sequence

2.1 Overview

There is no question that focusing solar collector reflector surface support panels can be fabricated from FRPH. Two major issues need to be addressed in the investigation. Is it technically feasible to produce parts with the specific geometric profiles required to provide the collector efficiency necessary? The second equally important issue is the cost and affordability question. If FRPH support panels are not cost competitive, then their future application is unlikely.

This study may not fully resolve the question of profile control and overall collector efficiency since it is only the first step in the development cycle. However, the test results on these panels will provide insight into the general quality of the panels and if the panels are reasonably efficient in terms of solar collection ability, the test results should suggest the nature of any deficiencies and make clear the probability of future success.

Likewise, while costs of collector panels of various geometries may not provide final cost data, it is probable that enough useful data will be collected to allow the estimation of fixed costs on future low quantity orders and close estimates on quantity production. This data will, of course, be essential to guide future development activities.

The project sequence here will provide as much information as feasible relative to both solar collection efficiency and the cost issues.

2.2 Polymer Shrinkage Tests

The strategy of the polymer shrinkage tests will be to test a limited number of materials that suppliers recommend as possessing as closely as possible zero shrinkage or expansion during curing cross-link. Several resin producers and suppliers sell tooling resins that are specifically designed for minimal shrinkage mold making. The program investigation will be directed toward these resins and fillers that will minimize mold and fabricated part shrinkage.

2.3 Materials Selection and Description of Mold Fabrication

2.3.1 Mold Materials

The priority consideration for mold materials, both resins and additives, will be directed toward minimizing mold shrinkage and resultant changes in mold profile. All other polymer characteristics should be adequate. If plaster is chosen, the limitations of its adhesive properties must be taken into consideration. Shrinkage is sufficiently low as not to pose a significant problem. Consideration will be given to the fact that polymer concrete molds are more rugged and flexible. These are two important advantages. For a given polymer concrete mold, many more parts can be produced and , when built with a suitable frame, profile adjustments can be made easily.

2.3.2 Collector Segment Materials

Fiberglass reinforced polyester or vinyl ester resins could be used for this initial study. However, it was decided to limit the study to polyester resins as they are approximately one-half the cost per pound of polyesters. On the other hand, if panels were needed that provided for profile adjustments after installation, vinyl ester resins would possibly be the better choice due to their superior elastic properties.

Core and face laminates will both be produced with the same resins.

2.4 Geometric Selections

Both core height and panel surfaces will be selected on the best judgement basis since the requirements are not well defined. The issue is not panel strength, since all panels will primarily be designed for deflection as data becomes available. Actual strengths are typically five to ten times that required. The primary requirement should be stiffness, though this is often a function of the ancillary support structure.

All panels produced will be conservatively designed even though this increases cost to some extent.

Section 3.0
24in x 20in Parabolic Facet

3.1 Description of the Segment (Drawing Sand1-01)

The segment was rectangular in shape with a spherical contour. Overall dimensions were 20in x 24in. The structural panel was approximately 1.25-inch thick with a 1.25-inch flange making a total thickness of 2.5in. Holes were to be drilled in the flange to provide attachment to the existing support frame. The focal length was to be 10-meters.

3.2 Surface Curve

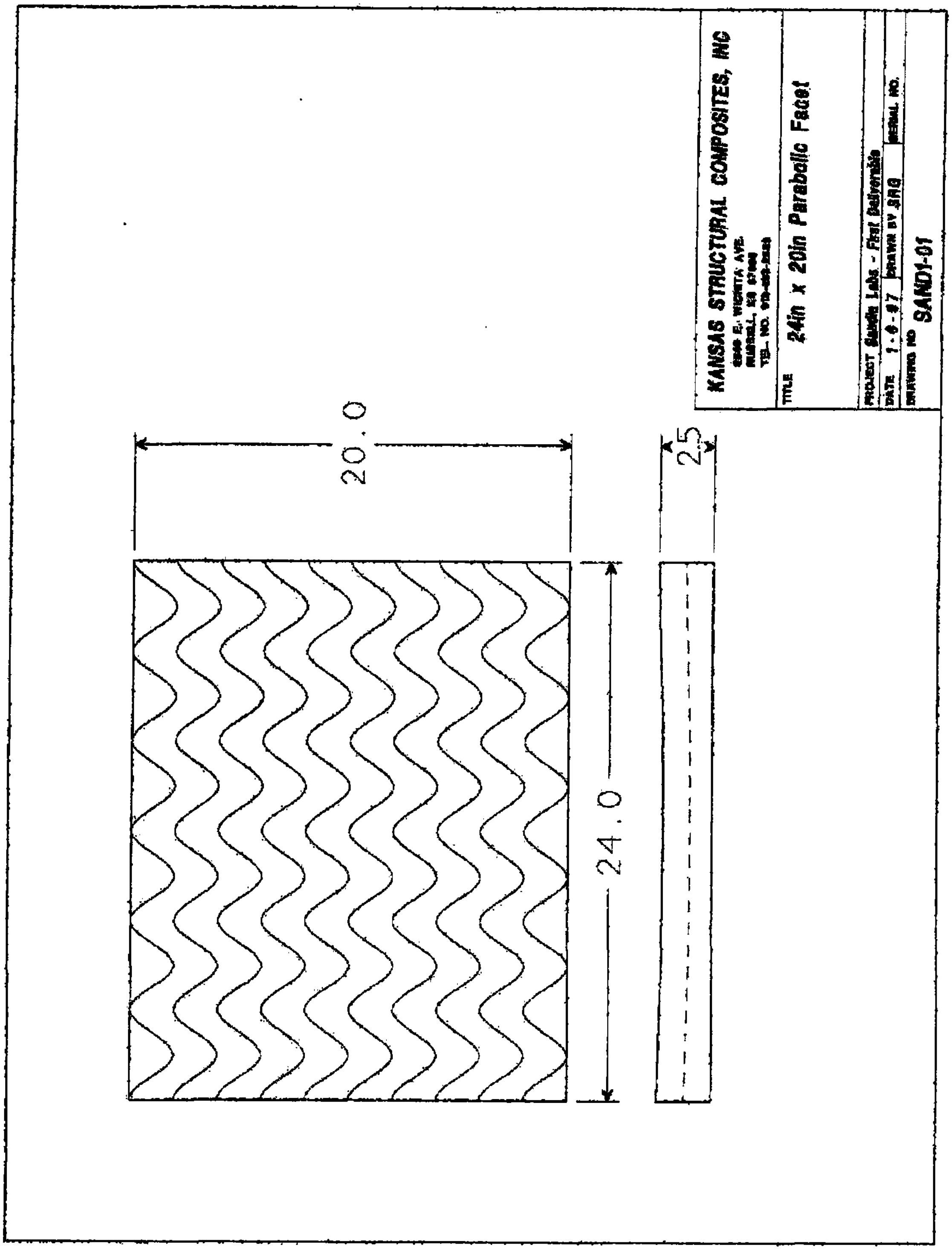
The tooling used for these samples was taken from an existing mold provided by Sandia Labs. No surface coordinates are provided.

3.3 Mold Construction Process

A female impression was made of the existing male mold using gypsum cement (plaster) as a base with a welded tube steel frame as a support and wire mesh to reinforce the plaster. A male mold was constructed from an impression of the female mold using the same materials. A joining ring was constructed of fiberglass laminate to provide an outer tooling surface for the flange.

3.4 Segment Manufacturing Process

The fiber-reinforced polymer (FRP) core was constructed prior to panel assembly. The laminate for the core was constructed using E-glass reinforcement in a polyester resin matrix. The reinforcing fabric was 0.75oz/ft2 chopped strand mat (CSM). The laminate was produced by a wet layup on a Mylar sheet. The Mylar/laminate was then formed into a fluted steel mold. After the laminate had cured, it was cut into strips by a diamond blade gang saw. The strips were replaced in the steel mold and an FRP stringer of E-glass roving bathed in resin was applied to the flute strips to maintain proper spacing during



KANSAS STRUCTURAL COMPOSITES, INC
TITLE 24in x 20in Parabolic Facet
PROJECT Sandia Labs - First Deliverable
DATE 1-6-97
DRAWN BY SRG
SERIAL NO.
DRAWING NO SAND1-01
20.0
24.0
2.5

assembly. The flute/stringer strips were cut to length and assembled by gluing the strips together until the proper panel width was achieved.

The glass reinforcement for the faces was pre-cut to the appropriate size. This includes the actual face dimension plus approximately two inches of additional material for the flanges. The laminate for the faces was also constructed using E-glass reinforcement. The matrix was polyester resin filled with 50% (by weight) calcium carbonate to limit shrinkage. The reinforcing fabric was 0.75oz/ft2 chopped strand mat (CSM).

The mold halves were sprayed with a polyvinyl alcohol (PVA) mixture to provide a release surface. The front face laminate was laid up on the female mold with the flange ring mounted. The core was impressed into the wet layup of the front face. The back face mold (with a wet layup applied) was inverted and impressed onto the front face/core assembly. The mold halves were then clamped together and the laminates allowed to cure.

After sufficient cure time, the molds were separated and the part removed. The flanges were then trimmed and the front face sanded in anticipation of application of the mirror surface.

20" x 24" Segment; Male Mold Section

20" x 24" Segment: Female Mold Section with Flange Ring

Section 4.0
10° Parabolic Gore Segment

4.1 Description of the Segment (Drawing Sand2-01)

This segment was part of the outer course of a segmented parabolic reflector. The segment was trapezoidal in shape with a parabolic surface contour. Overall length was 115.6in. The base (outer circumference) of the trapezoid was 52.5in. The length of the inner edge was 32.3in. The structural panel was approximately 2.0in thick with a 2-inch flange making a total thickness of 4.0in. Stamped-steel mounting brackets were supplied by Sandia Labs to be attached to the back face of the segment. The focal length was to be 364in.

4.2 Surface Curve

The surface coordinates used for the mold construction are given in the accompanying table. It was determined that the intersection of the paraboloid with any plane parallel to its axis generates the same parabolic curve as that used to generate the surface regardless of the radial distance from the axis. This fact was used to generate the mold surface.

The general equation of the surface is as follows:

$$z=\frac{r^2}{4f}$$

where:

$r^2 = x^2 + y^2$
f = 363.917in (focal length)

In the accompanying tables, the radial line that defines the edge was 0.25in inside of a line placed 5° on either side of the centerline of the segment. The equation used to generate the paraboloid coordinates is therefore as follows:

$$z=\frac{(x^2+y^2)}{4f}$$

where:

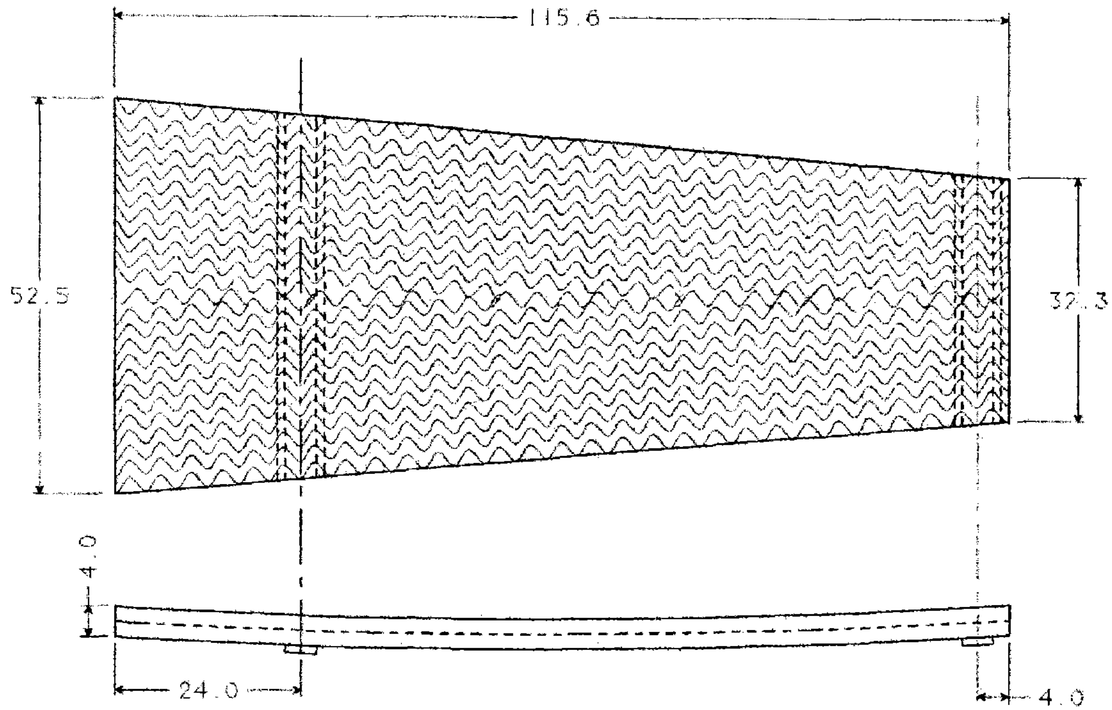
$y_{centerline} = 0$
$y_{edge} = x*\tan 5° - 0.25$
f = 363.917in (focal length)

The mold coordinates denote a translation of the origin from the apex of the paraboloid to the center of the inside edge of the segment. The reference plane is still normal to the paraboloid axis.

Table 4.1
Radial Coordinates Used for 10° Segment

Paraboloid Coordinates				Mold Coordinates		
	z-coordinate				z-coordinate	
x	centerline	edge		x	centerline	edge
187.021	24.028	24.206		0.000	0.000	0.178
193.021	25.595	25.785		6.000	1.566	1.757
199.021	27.210	27.413		12.000	3.182	3.385
205.021	28.876	29.091		18.000	4.848	5.063
211.021	30.591	30.819		24.000	6.563	6.790
217.021	32.355	32.596		30.000	8.327	8.568
223.021	34.169	34.424		36.000	10.141	10.396
229.021	36.032	36.301		42.000	12.004	12.273
235.021	37.945	38.228		48.000	13.917	14.200
241.021	39.907	40.205		54.000	15.879	16.177
247.021	41.918	42.232		60.000	17.890	18.204
253.021	43.980	44.309		66.000	19.952	20.281
259.021	46.090	46.435		72.000	22.062	22.407
265.021	48.250	48.612		78.000	24.222	24.583
271.021	50.460	50.838		84.000	26.432	26.810
277.021	52.719	53.114		90.000	28.690	29.086
283.021	55.027	55.440		96.000	30.999	31.412
289.021	57.385	57.815		102.000	33.357	33.787
295.021	59.792	60.241		108.000	35.764	36.213
301.021	62.249	62.716		114.000	38.221	38.688
302.110	62.700	63.171		115.089	38.672	39.143

Z-coordinates are measured from planes normal to the axis of the paraboloid.



KANSAS STRUCTURAL COMPOSITES, INC
2649 E. WICHITA AVE.
RUSSELL, KS 67665
TEL. NO. 913-483-2589

TITLE **10° Parabolic Segment**

PROJECT *Sandia Labs - Second Deliverable*

DATE 1-8-97 | DRAWN BY SRG | SERIAL NO.

DRAWING NO. **SAND2-01**

Table 4.2
Coordinates Used for Constructing the Screed

Screed Coordinates	
y	z-coordinate
0	0.000
2	0.003
4	0.011
6	0.025
8	0.044
10	0.069
12	0.099
14	0.135
16	0.176
18	0.223
20	0.275
22	0.332
24	0.396
26	0.464
28	0.539

Y-coordinates are measured from the centerline of the segment
Z-coordinates are measured from planes normal to the axis of the paraboloid

4.3 Mold Construction Process

It was determined that the easiest way to generate the mold surface would be to generate the surface with two curves. Two identical radial side rails were shaped to a parabolic curve from aluminum plate. These were attached to a steel tube frame at +/- 5° to the segment centerline. The frame was then bolted to the floor and leveled. The screed was also shaped from aluminum plate using the same parabolic curve.

The floor of the mold was constructed of 3/4-inch plywood coated with polyester resin to repel moisture. A bed of polymer impregnated paper honeycomb was attached to the plywood and formed to the general shape of the surface. Gypsum cement was then poured over the paper core and screeded. The screed was set across the side rails and pulled along the centerline of the segment. Thus the radial curvature was determined by the side rails and the tangential shape was determined by the screed. Successive layers of plaster were then screeded to the mold to give a final shape.

Surface irregularities were eliminated with auto body putty. A number of primer paint coats were applied and sanded to a smooth finish. The surface was sealed with a

10° Parabolic Segment Mold

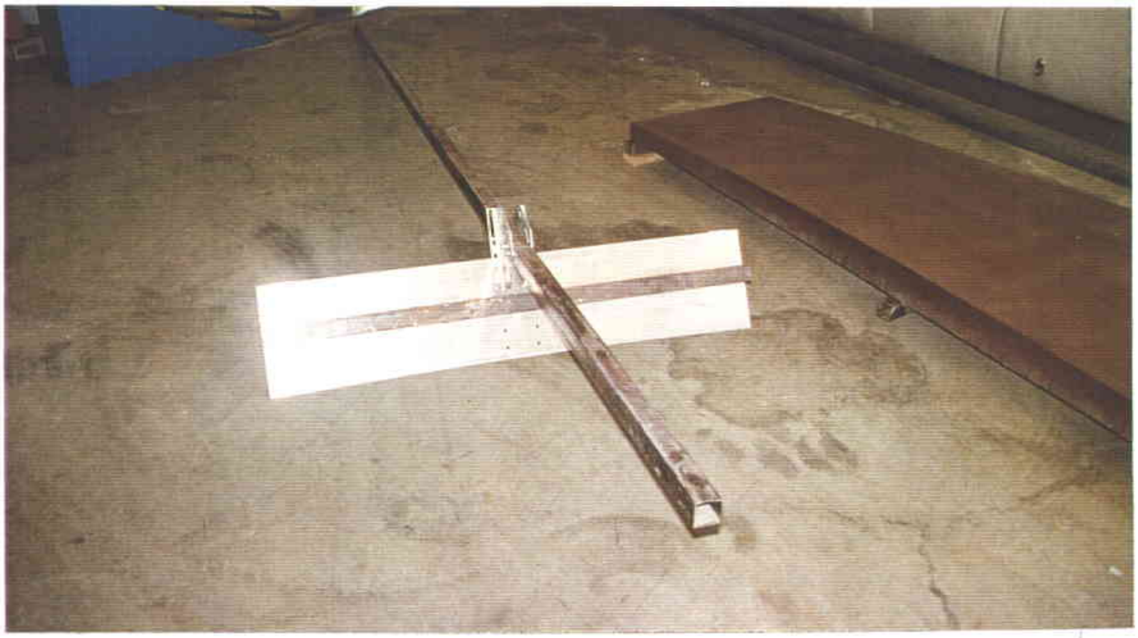
urethane finish coat.

An impression of the finished mold was taken to provide a mold for the back face of the part. This mold was made from an E-glass/polyester laminate.

4.4 Manufacturing Process

Construction of the segment followed a procedure similar to that used on the 20in x 24in segment. The only modifications to this procedure were the construction of a cured pre-skin attached with a wet bonding laminate to counteract the dimpling effect associated with shrinkage of the faces around the core webs and the use of less filler in the resin for the faces to improve wet out.

The core was again laminated using E-glass reinforcement in a polyester resin matrix. The reinforcing fabric was 0.75oz/ft^2 chopped strand mat (CSM). The laminate is produced by a wet layup on a Mylar sheet. The Mylar/laminate is then formed into a fluted steel mold. After the laminate has cured, it is cut into strips by a diamond blade gang saw. The strips are replaced in the steel mold and an FRP stringer of E-glass roving bathed in resin was applied to the flute strips to maintain proper spacing during assembly. The flute/stringer strips are cut to length then assembled by gluing the strips together until the



Screed Used to Form 10° Segment Mold Surface

proper panel width is achieved. It can be seen from the drawing that the core was assembled in a 'V' arrangement rather than creating a rectangular shape and then being required to cut the result to the trapezoidal shape. It was felt that this would eliminate a certain amount of material waste.

The glass reinforcement for the faces is pre-cut to the appropriate size. This includes the actual face dimension plus approximately four inches of additional material for the flanges. The laminate for the faces was also constructed using E-glass reinforcement. The matrix was polyester resin filled with 40% (by weight) calcium carbonate to limit shrinkage. The amount of filler was less for this segment as it had been discovered that 50% fill caused great difficulty in wetting the thicker laminate used for the faces. The reinforcing fabric was 2.0oz/ft^2 chopped strand mat (CSM) for both the pre-skin and the bonding layers for the faces giving a total reinforcement weight of 4.0oz/ft^2.

FRP side fences were attached to the mold to form a mold surface for the edges and flange. The front face pre-skin laminate was laid into the mold and allowed to cure. This produced a smooth surface. The bonding layer was laid-up on the back of the pre-skin and the core impressed into the wet layup. The back face pre-skin was laid-up on the previously constructed FRP impression and allowed to cure. The bonding layer was then applied to this skin and the assemblage was inverted and impressed on the front face/core assembly. Vacuum pressure was then applied to the entire mold assembly until the bonding laminate had reached a gelled state. The vacuum was removed and the part was allowed to cure.

Finally, the pressed steel brackets provided by Sandia were attached to the back of the part with a methacrylate aerospace adhesive. The part was removed from the mold and finished.

Section 5.0
3-meter Parabolic Dish

5.1 Description of the Dish (Drawing Sand3-01)

The part was circular in shape with a parabolic surface contour. Overall diameter was 126in. The structural panel was approximately 4.0in thick with no flange. Steel mounting brackets with floating adjusting nuts were supplied by Sandia Labs to be attached to the rim of the part at 120° spacing. The focal length was to be 10.6 meters (417.5in).

3-Meter Mold Showing Support Structure
and Screed Apparatus

5.2 Surface Curve

The surface coordinates used for the mold construction are given in the accompanying table. The general equation of the surface is as follows:

$$z = \frac{r^2}{4f}$$

where:

r = radial distance from the apex
f = 417.323in (focal length)

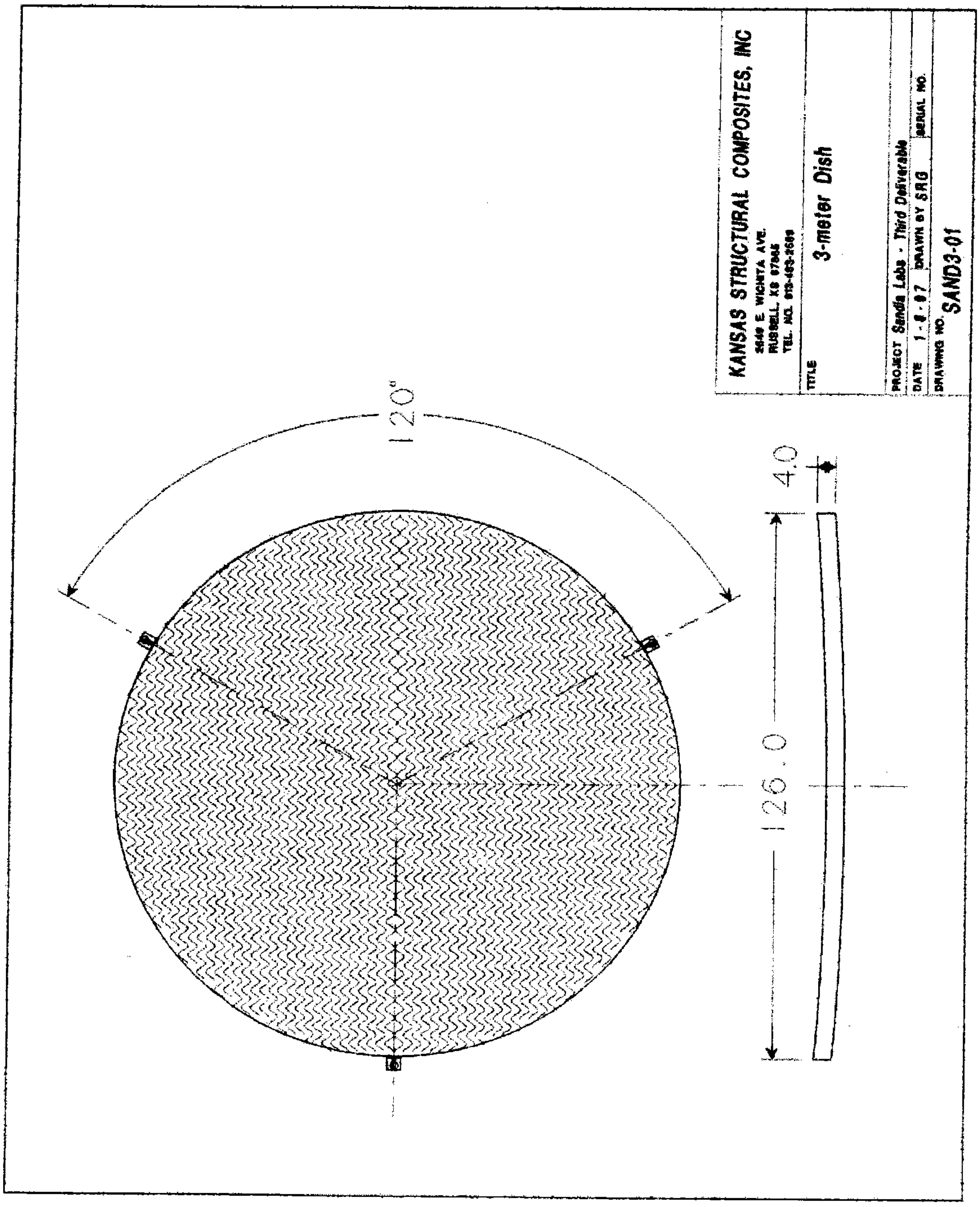
5.3 Mold Construction Process

It was determined that the easiest way to generate the required surface would be to revolve a screed of the proper curvature about the axis of the paraboloid. The base of the mold was constructed in a similar fashion to the 10° segment. A tube steel frame was constructed as a support structure. This frame was supported approximately three feet off the floor. Sealed plywood was attached to the tube frame and paper honeycomb core was attached to the plywood and shaped to the general curve of the dish. The screed was fashioned from aluminum plate and shaped to the coordinates in the accompanying table. The screed was attached to an axle that pivoted in a bushing beneath the center of the mold platform. Gypsum cement was poured on top of the paper honeycomb and screeded to the general shape of the mold. The mold was then surfaced with a filled polyester resin and the axle hole filled. The surface was sealed with a urethane finish coat.

5.4 Manufacturing Process

The back face of the dish was constructed first. The laminate was laid up on the mold and allowed to cure, then removed to await final assembly.

The core was manufactured as previously described. The core was again laminated using E-glass reinforcement in a polyester resin matrix. The reinforcing fabric was 1.0oz/ft^2 chopped strand mat (CSM). The laminate is produced by a wet layup on a Mylar sheet. The Mylar/laminate is then formed into a fluted steel mold. After the laminate has cured, it is cut into strips by a diamond blade gang saw. The strips are replaced in the steel mold and an FRP stringer of E-glass roving bathed in resin was applied to the flute strips to maintain proper spacing during assembly. The core was assembled in approximately 12in wide segments to facilitate the final assembly and cut to shape on the mold.



KANSAS STRUCTURAL COMPOSITES, INC
TITLE
3-meter Dish
PROJECT Sandia Labs - Third Deliverable
DATE 1-8-97
DRAWN BY SRG
SERIAL NO.
DRAWING NO. SAND3-01
120°
4.0
126.0

Table 5.1
Coordinates Used for Construction of the 3-meter Dish

Paraboloid Coordinates	
r	z-coordinate
0	0.000
2	0.002
4	0.010
6	0.022
8	0.038
10	0.060
12	0.086
14	0.117
16	0.153
18	0.194
20	0.240
22	0.290
24	0.345
26	0.405
28	0.470
30	0.539
32	0.613
34	0.693
36	0.776
38	0.865
40	0.958
42	1.057
44	1.160
46	1.268
48	1.380
50	1.498
52	1.620
54	1.747
56	1.879
58	2.015
60	2.157
62	2.303
64	2.454

A side fence was attached to the mold to form the edge closeout. The front face pre-skin laminate was laid-up in the mold and allowed to cure. Due to the short working time exhibited by the resin, the bonding layer was laid-up in sections. A wet laminate was applied to the pre-skin and a core segment was impressed into it. This section was weighted with sand over a polyethylene sheet and the next section was laid out. This process was continued across the part until the full core layer was constructed. In this way, proper bonding of the earlier core segments was ensured while fabrication continued. After this assembly had cured, a bonding laminate was applied to the back face. This face/bonding laminate was applied to the core and weighted with sand as previously described.

The part was then trimmed and finished and the mounting brackets attached with methacrylate adhesive.

Section 6.0
4ft x 16ft Spherical Segment

6.1 Description of the Segment (Drawing Sand4-01)

The part was rectangular in shape with a spherical surface contour. Overall dimensions were 192in x 48in. The structural panel was approximately 4.0in thick with a 2.0in perimeter flange making an overall panel thickness of approximately 6in. Steel mounting brackets with adjustable studs were attached to the back surface. The focal length was to be 1000ft.

4' x 16' Mold

6.2 Surface Curve

The general equation of the surface is The surface coordinates used for the mold construction are given in the accompanying table. as follows:

$$z=\sqrt{r^2-x^2-y^2}$$

where:

r = 2*f
f = 12000in (focal length)

6.3 Mold Construction Process

A previously untried mold construction process was used for this section of the project. A polymer concrete material was used as the basis for the mold rather than gypsum cement. The mold curvature was generated in a manner similar to that used for the 10° segment. Two parallel steel tube side rails were attached to a platen. These rails were shimmed to the desired longitudinal curvature. The lateral curvature of the segment was determined by the screed. The frame was filled with a polymer concrete mixture and screeded to form the general curvature of the mold. Three layers of a highly filled polyester resin were then screeded over the polymer concrete. This surface was primed and sanded smooth before being sealed with a urethane finish coat.

6.4 Manufacturing Process

The core was manufactured as previously described. The core was laminated using E-glass reinforcement in a polyester resin matrix. The reinforcing fabric was 1.0oz/ft2 chopped strand mat (CSM). The laminate is produced by a wet layup on a Mylar sheet. The Mylar/laminate is then formed into a fluted steel mold. After the laminate has cured, it is cut into strips by a diamond blade gang saw. The strips are replaced in the steel mold and an FRP stringer of E-glass roving bathed in resin was applied to the flute strips to maintain proper spacing during assembly. The core was assembled to the full 48in width.

A wet layup was applied to the mold to form a pre-skin and flanges for the mirror face. A wet secondary bonding layer was applied to the pre-skin and the previously constructed core layer was impressed into the face with vacuum. After cure, the front face and core assembly was removed from the mold and the back pre-skin was constructed.

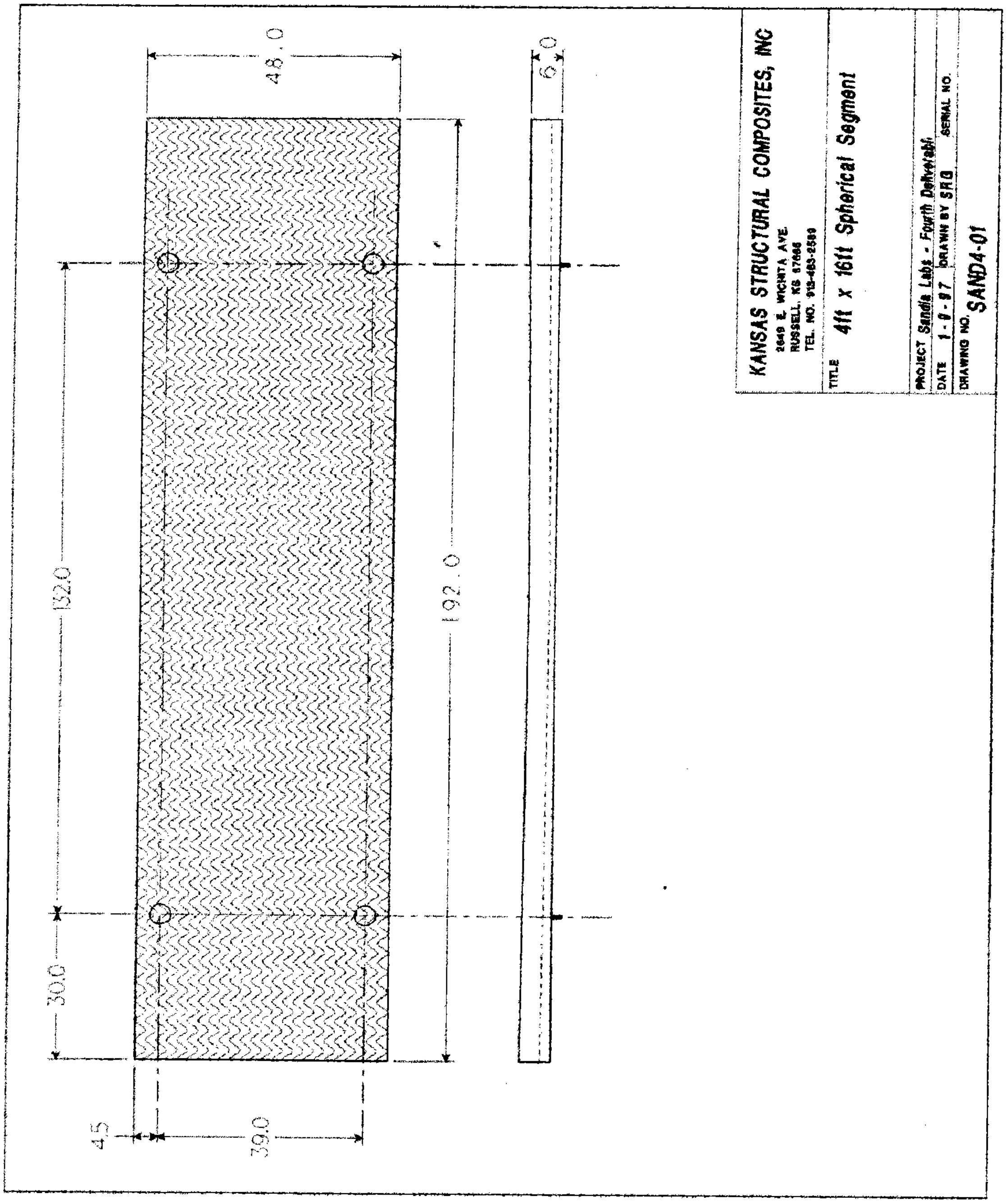

48.0
6.0
132.0
192.0
30.0
4.5
39.0
KANSAS STRUCTURAL COMPOSITES, INC
TITLE
4ft x 16ft Spherical Segment
PROJECT Sandia Labs - Fourth Deliverable
DATE
DRAWN BY SRG
SERIAL NO.
DRAWING NO. SAND4-01

Table 6.1
Coordinates for the 4ft x 16ft Spherical Segment

y (width) across the columns; x (length) down the rows.

x (length) \ y (width)	24	18	12	6	0	-6	-12	-18	-24
96	0.000	0.005	0.009	0.011	0.012	0.011	0.009	0.005	0.000
90	0.023	0.029	0.032	0.035	0.035	0.035	0.032	0.029	0.023
84	0.045	0.050	0.054	0.056	0.057	0.056	0.054	0.050	0.045
78	0.065	0.071	0.074	0.077	0.077	0.077	0.074	0.071	0.065
72	0.084	0.089	0.093	0.095	0.096	0.095	0.093	0.089	0.084
66	0.101	0.107	0.110	0.113	0.113	0.113	0.110	0.107	0.101
60	0.117	0.122	0.126	0.128	0.129	0.128	0.126	0.122	0.117
54	0.131	0.137	0.140	0.143	0.143	0.143	0.140	0.137	0.131
48	0.144	0.149	0.153	0.155	0.156	0.155	0.153	0.149	0.144
42	0.155	0.161	0.164	0.167	0.167	0.167	0.164	0.161	0.155
36	0.165	0.170	0.174	0.176	0.177	0.176	0.174	0.170	0.165
30	0.173	0.179	0.182	0.185	0.185	0.185	0.182	0.179	0.173
24	0.180	0.185	0.189	0.191	0.192	0.191	0.189	0.185	0.180
18	0.185	0.191	0.194	0.197	0.197	0.197	0.194	0.191	0.185
12	0.189	0.194	0.198	0.200	0.201	0.200	0.198	0.194	0.189
6	0.191	0.197	0.200	0.203	0.203	0.203	0.200	0.197	0.191
0	0.192	0.197	0.201	0.203	0.204	0.203	0.201	0.197	0.192
-6	0.191	0.197	0.200	0.203	0.203	0.203	0.200	0.197	0.191
-12	0.189	0.194	0.198	0.200	0.201	0.200	0.198	0.194	0.189
-18	0.185	0.191	0.194	0.197	0.197	0.197	0.194	0.191	0.185
-24	0.180	0.185	0.189	0.191	0.192	0.191	0.189	0.185	0.180
-30	0.173	0.179	0.182	0.185	0.185	0.185	0.182	0.179	0.173
-36	0.165	0.170	0.174	0.176	0.177	0.176	0.174	0.170	0.165
-42	0.155	0.161	0.164	0.167	0.167	0.167	0.164	0.161	0.155
-48	0.144	0.149	0.153	0.155	0.156	0.155	0.153	0.149	0.144
-54	0.131	0.137	0.140	0.143	0.143	0.143	0.140	0.137	0.131
-60	0.117	0.122	0.126	0.128	0.129	0.128	0.126	0.122	0.117
-66	0.101	0.107	0.110	0.113	0.113	0.113	0.110	0.107	0.101
-72	0.084	0.089	0.093	0.095	0.096	0.095	0.093	0.089	0.084
-78	0.065	0.071	0.074	0.077	0.077	0.077	0.074	0.071	0.065
-84	0.045	0.050	0.054	0.056	0.057	0.056	0.054	0.050	0.045
-90	0.023	0.029	0.032	0.035	0.035	0.035	0.032	0.029	0.023
-96	0.000	0.005	0.009	0.011	0.012	0.011	0.009	0.005	0.000

The front face/core assembly was then reinstalled in the mold. The back pre-skin was laid on the front assembly with a layer of chopped strand mat. One end of the skin and mat were rolled back and the mat wetted to produce the bonding layer. The other end was rolled back and wetted then the entire assembly was cover by a polyethylene sheet and weighted with sand until the back bonding layer had cured. The part was then removed from the mold and finished and the mounting brackets attached to the rear face with epoxy adhesive.

Section 7.0
Observations, Findings, and Recommendations

Section 7.1 Observations on the Manufacturing Process

7.1.1 Polymer Shrinkage

The resin used for the samples was isophthalic polyester filled with either calcium carbonate or hydrated alumina (aluminum trihydrate) to control shrinkage and the resultant distortion of the faces. Results for a two cast resin sample are given in Table 7.1. No data is available for shrinkage of reinforced laminates. Shrinkage for the smaller samples was not as much of a problem but, as the overall dimensions of the facets increased, distortion of the panels became more noticeable.

Table 7.1

Filled Polymer Resin Shrinkage

% $CaCO_3$ Fill	% Shrinkage	Density (lb/in^3)
40	1.8	.0546
50	0.8	.0590

This is particularly true of samples where the two faces were not molded simultaneously. Whereas simultaneous face layup is not practical for the larger panels the initial cured face may have the proper curvature, but the shrinkage of the second face causes the panel to deform. This distortion is critical for focusing of panels with lesser curvatures. A shrinkage of 0.5% over 16ft (the length of the final panel) would produce a 1in change in overall length of the face. The change in radius of curvature is an inverse function of the included angle of the facet. The included angle for relatively flat panels is very small, consequently the change in the radius of curvature (and therefore the location of the focal point) is great. One solution for this is to allow the panel to fully cure in the mold, but this would limit production volumes considerably. And, given the inconsistency of production laminates so far as resin/reinforcement ratios ,etc. are concerned, repeatability would be difficult to achieve, at least at this point in development. Another solution would involve building a flexible reflector panel that could be adjusted to the desired focus in the mounting fixture. This would be particularly appropriate for long focal lengths as the actual equation of the surface is not so important as the location of the focal point.

7.1.2 Core Geometry Selection

While the open-cell core has definite advantages as far as conforming to curved surfaces and is light-weight, it is difficult to handle, especially for large panels. The flexible nature of the core blanket does not lend itself to easy manipulation.

7.1.3 Wetting-Out of Reinforcing Materials

The laminates produced with filled resin were particularly difficult to wet out. The solution was to pre-wet the mold surface and roll the reinforcement into the resin rather than use the more conventional method off applying resin to the reinforcement. The higher viscosity of the filled resin tended to entrap air in the laminate and seemed to inhibit breakdown of the binder used in the reinforcement. This made roll-out of the laminate more difficult, particularly on vertical surfaces, and produced a higher percentage of voids than might normally be seen.

7.1.4 Resin-Promoter Levels

Another difficulty encountered was the short working time of the resin. This was adjusted by varying the promoter levels in the resin and utilizing different catalyst systems and should not constitute a major obstacle to production.

7.1.5 Plaster as a Mold Material

Gypsum cement (plaster) was used as a base for all mold surfaces save the last. Plaster has the desirable property of very low shrinkage during cure. However, it also has very low adhesion to most materials, including itself. This made the application of multiple layers difficult, especially for the larger molds. There was evidence of delamination of the molds for both the 10° facet and the circular dish. The major problem seems to be the inability to pour continuously. This was because of a dirth of large scale mixing equipment. Consistent batching of plaster is dependent on water content, temperature and humidity, and time. These variables were difficult to control in the current shop environment. We also found no material save auto body filler (a highly filled polyester resin) that would adhere to the plaster base of the mold. This might have worked well had the shop area been temperature controlled. Large temperature variation in the shop area caused a differential expansion and contraction of the constituent materials and a consequent delamination of both plaster and surfacing layers over time.

The two original molds for the second and third deliverables for this project did not exhibit any longevity whatsoever. The gypsum cement substrata did not exhibit either adhesive or cohesive properties and these substrata delaminated after only one or two parts were pulled from the mold. They also deteriorated over time due to the large temperature changes in the manufacturing area. It was mandatory that we determine a new mold making process and rebuild these molds.

7.1.6 Resin-Mold Surface Compatibility

There was a degree of incompatibility between the mold surfacing layers and the part resin in some cases. The trapezoidal segment was originally surfaced with a laquer. When the back face mold impression was taken, this paint de-bonded from the base lamina and wrinkled leaving a rough surface on the cured laminate. This problem was subsequently solved by the use of the urethane finish coats which exhibited an excellent degree of resistance to the laminating resins and adequate adhesion to the underlying mold materials.

Section 7.2 Revised Mold Construction Method

The rectangular mold constructed for the 4ft x 16ft spherical segment did not use plaster as a base material. Polymer concrete was used as the basis for this mold. It was overlaid with two applications of filled polyester resin to form a relatively smooth surface that was then smoothed with body filler before being primed and painted with the final mold surface. This construction method provided a durable and tough tool. There was no deterioration of the tooling surface or the substrate as with the plaster molds. Loading of the tool onto carts and subsequent transportation to another part of the facility was accomplished without observable damage even though there was no support frame under the polymer concrete base.

Given the deteriorated state of the other two large molds, it was decided to repair them using the method described above. The plaster and substrata of the trapezoidal mold were removed and a plywood substructure was built up on the existing steel framework. The plywood was stepped to form a rough approximation to the desired curve of the mold. A layer of polymer concrete was applied over the plywood. This initial layer contained a relatively coarse aggregate. It was observed after cure of this layer that cracks had developed in the concrete due to shrinkage of the polymer particularly around the steps in the plywood base. There was also some slumping as evidenced by a gap between the screed and the surface after curing. It is marginally important for the concrete to have minimal slump in order to maintain the desired curvature and provide a consistent base for subsequent laminae. A second layer of polymer concrete composed of finer aggregate was applied in a layer approximately .200in thick. The initial coarse layer was relatively dry when compared with the second layer. This layer showed no signs of cracking or shrinkage though there was evidence of slump. The final two substrata were polyester resin mixed with Cabosil, a thixotropic additive, to minimize flow. It was observed that the first such layer exhibited some slumping. The second layer was mixed with a higher ratio of filler. This eliminated slumping. Shrinkage appears to be minimal in these layers due to good adhesion to the stable polymer concrete base. The final curve of the mold matched that of the screed within the limits of our ability to measure it. The filled surface was then smoothed with body filler and primed.

The 3-meter dish mold was repaired in a similar fashion. The only difference between the molds was the construction of the substructure. In order to save material, the base was built up using paper honeycomb core and thin plywood. The sheets were attached with screws through the plywood and paper into the lower layers in an attempt to create a sandwich structure for stiffness and stability. The application of the initial polymer concrete layer showed that our efforts had been inadequate. The shrinkage of the concrete caused the plywood layers to warp and delaminate, particularly at the edge of the mold. These areas were reattached with heavier lag screws and the subsequent layer of fine aggregate did not exhibit this problem. This problem, while a detriment to the described mold, provided useful information for subsequent tool construction. It is imperative, especially for molds with large areas, to provide a stable framework to counteract the shrinkage of the polymer layers. This is the one area where plaster has an advantage. Shrinkage is kept to a minimum. However, the capital expenditure required for material handling equipment for large volumes of plaster as would be required for molds of this size would be difficult for a small scale operation. Polymer concrete can be applied in small batches because it has good cohesive properties. This seems impossible to accomplish with plaster. Various methods were tried to get layers of plaster to adhere to each other and none proved adequate.

TECHNICAL DATA

#10 WHITE

Fine Calcium Carbonate Filler

#10 White is a medium fine particle size, ground calcium carbonate filler with a good white color. It is widely used in paints, wall sealants, caulks, floor and ceiling tile, plastics, putties, non-blocking agents, wall and floor mastics, and thermoplastic/thermoset compositions. It is also useful as an additive for natural and synthetic rubber and spray-up sanitary ware.

TYPICAL PROPERTIES

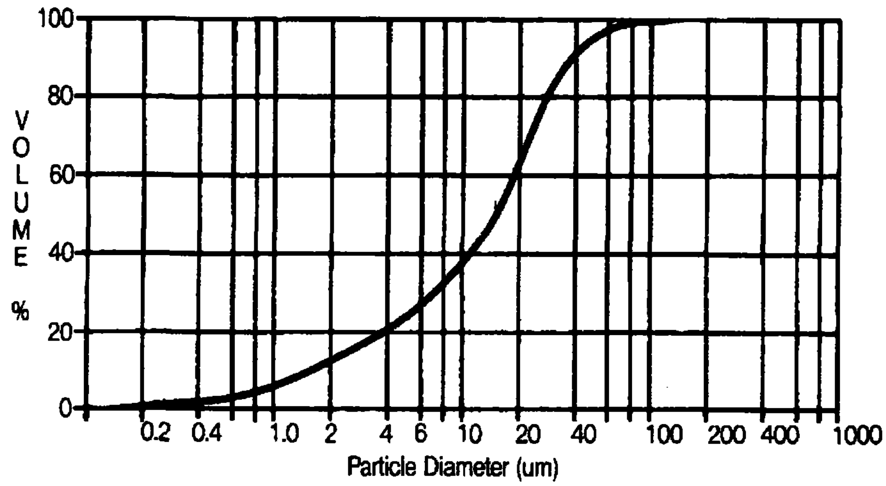
Chemical Composition

Calcium Carbonate ($CaCO_3$)%	58.3%
Magnesium Carbonate ($MgCO_3$)%	40.5%
Silica Dioxide (SiO_2) %	.2-.8%

Physical Properties

% Retained on wet 325 Mesh	0.8±2
Specific Gravity	2.7
Hardness (Moh's Scale)	3.0
Dry Brightness	93

PARTICLE SIZE DISTRIBUTION



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Being products of nature, some variations may occur due to strata changes of natural deposits. Data as outlined represents constant quality control instigated to control nature's material within given limits as outlined. However, no warranty is expressed or implied that nature's variations can consistently be controlled.

Basins, Inc.

INDUSTRIAL PRODUCTS

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8/93/250

REICHHOLD

PRODUCT BULLETIN

POLYLITE® 33166-00 SERIES

DESCRIPTION

The Polylite 33166-00 series of resins was developed for low-color laminating applications that require the addition of specific carbonate, hydrate, or sulfate type fillers. These low-viscosity, low-profile, thixotropic resins are pre-promoted for room temperature gel and cure upon the addition of methyl ethyl ketone peroxide (MEKP). A paraffin-based surfacing agent has been added to reduce VOC emissions.

FEATURES	*BENEFITS*
• Paraffin-based surfacing agent added	• Reduced air inhibition
• Good profile characteristics	• Minimal print-through of reinforcements
• Versatile	• Suitable for spray-up as well as hand lay-up applications
• Rapid cure rate	• Short cycle times and fast production rates
• Excellent handling properties	• Rapid wet-out of reinforcements • Reduced voids and resin-starved areas
• Low viscosity	• Accepts specific fillers at levels up to 33%
• High thixotropic index	• Resists sagging or draining on vertical surfaces • Resists drainage from reinforcements
• SPC/SQC controlled	• Uniform performance, batch to batch

VERSIONS

• Polylite 33166-05	• *Complies with Rule 50 and Rule 1162 regarding VOC emissions* • Typical viscosity: 150 cps • Typical gel time: 11 minutes
• Polylite 33166-10	• Complies with Rule 1162 and Rule regarding VOC emissions • Typical viscosity: 150 cps • Typical gel time: 22 minutes

SIMILAR RESINS

Consult your Reichhold sales or technical service representative or authorized distributor for information on similar resins.

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REICHHOLD CHEMICALS, INC. • RESEARCH TRIANGLE PARK, NC 27709 • (919) 990-7500

TYPICAL[1] LIQUID PROPERTIES @ 25°C

	TEST METHOD	
Flash Point, Seta Closed Cup, °C (°F)		31.6 (89)
Shelf Life minimum, months*		3
Specific Gravity		1.08
Weight, lbs/gal	18-030	9.0
Styrene Monomer, %	18-001	39
Viscosity, Brookfield LVF #2 Spindle @ 60 RPM, cps	18-021	355
Thixotropic Index	18-021	3.0
Gel Time† minutes	18-050	21.5
Gel Time to Peak Exotherm, minutes	18-050	13.5
Peak Temperature, °C (°F)	18-050	170 (338)
Color, Liquid	18-043	Pink, opaque

* See following section on storage procedures.
†With 1.25 g Lucidol DDM-9 per 100 g resin.

APPLICATION

Polylite 33166-00 is pre-promoted, so the addition of Lucidol DDM-9 methyl ethyl ketone peroxide (MEKP) will bring about room temperature gel and cure. As with all polyesters, time and degree of cure are functions of catalyst concentration and of temperature. Resin temperatures and work areas should be maintained between 24 and 35°C (75-95°F) to ensure satisfactory results. Lucidol DDM-9 initiator levels should be maintained within a range of 0.75 to 2.5% based on resin weight. Using initiator levels outside of this range may result in inadequate cure, with laminates exhibiting moderate to severe post-cure after demolding. If alternative gel times are required, contact your Reichhold representative to determine products available for special requirements.

Certain procedures should be followed when using Polylite 33166-00 to ensure proper secondary bond performance. The rapid cure rate of the resin requires uninterrupted application of laminates. The styrene suppressant in Polylite 33166-00 series resins may influence secondary bond performance. The substrate should be thoroughly scuff sanded prior to application of secondary bond. Secondary bonding will also be adversely affected in resin-rich areas or in laminates that have been exposed to heat or direct sunlight for an extended period of time. Should such conditions occur, thorough sanding and cleaning of the substrate is recommended prior to secondary laminate application. Other conditions known to affect secondary bond performances are contamination of the primary laminate (e.g., grinding dust, oil, moisture, waxes, release agents, etc.) and type of glass reinforcement used. All contaminants should be removed from the laminate surface prior to secondary bond application.

Each user must determine the suitability of this product in their particular mode of operation.

[1]Properties listed in this bulletin are typical of those obtained in controlled laboratory tests and are provided as guidelines