INVESTIGATION OF GLASS-METAL COMPOSITE MATERIALS

EIGHTH QUARTERLY PROGRESS REPORT

COVERING PERIOD JUNE 15, 1957 to SEPTEMBER 15, 1957

CONTRACT NOrd 15764

by

HERBERT B. AILES
GLASS-METALS RESEARCH LABORATORY

SEPTEMBER 30, 1957

OWENS-CORNING FIBERGLAS CORPORATION
Basic and Applied Research Center
Newark, Ohio

TABLE OF CONTENTS

I INTRODUCTION

The major efforts during the period covered by this report (June 15 to September 15, 1957) have been in the following directions:

A. Improving existing and investigating new methods of forming and working composites of aluminum and aluminum coated glass fibers.

B. Determining a complete set of physical data on a standard glass-reinforced aluminum composite in order to indicate the general characteristics of glass-reinforced metals as a class of materials.

C. Developing a method of forming composites of aluminum and bare glass fibers and evaluating the physical properties of these composites.

D. Production and testing of glass-reinforced aluminum tubular shapes.

E. Developing a theory on the interaction of metals and glass fibers.

F. Developing a glass-reinforced metal having utility at temperatures above 1000°F.

The work reported represents the combined efforts of Messrs. J. I. Aber, R. E. Evans, B. B. Garick, P. A. Lockwood, H. E. Mathews, E. E. Mattern, C. A. Riesbeck, E. W. Smart, R. S. Swain, G. E. Wince, and the author, of the Glass-Metals Research Laboratory, and Dr. H. B. Whitehurst, Department Head. Acknowledgement is also made of the valuable assistance given by many other members of the Basic and Applied Research Center.

Physical property measurements of the glass-reinforced metal test bars were performed by the Olin-Mathieson Chemical Corporation in New Haven, Connecticut, and by the Ohio State Engineering Experiment Station of the Ohio State University in Columbus, Ohio.

Work on fabrication of large shapes, in particular tubing, of glass-reinforced metals has been subcontracted to the Olin-Mathieson Chemical Corporation in New Haven, Connecticut.

The expiration date of this contract is October 31, 1957. Negotiations have been opened with the Navy Bureau of Ordnance to extend this contract for one year.

II SUMMARY

The average compressive ultimate strength of the standard glass-reinforced aluminum composite is 128,000 psi at room temperature. Unreinforced 14S aluminum has a compressive yield strength of 60,000 psi at room temperature. A compressive yield strength could not be determined for the glass-reinforced aluminum using available equipment.

The Olin-Mathieson group has investigated the process variables, materials characteristics, and process dynamics of the centrifugal casting procedure for fabrication of glass-reinforced aluminum tubes. Over a wide range of experimental conditions, the interdependent relationships between certain of these factors have precluded the attainment of wholly satisfactory tubes. Laboratory work was undertaken concurrently with centrifugal casting experiments in order to overcome materials weaknesses and eliminate or modify undesirable process dynamics. The results of this work have been encouraging enough to warrant further efforts in this direction.

The combination of most metals and glass fibers results in some degradation in the strength of the glass fibers. Experiments on combinations of glass fibers with Wood's metal, lead, zinc, and aluminum have indicated that this strength degradation increased with increasing temperature at which the glass and molten metal are contacted. However, there is no definite indication as to whether the fiber strength degradation is due to chemical, thermal, or mechanical reaction of the metal upon the fiber. A clearer understanding of this interaction will point the way to large improvements in glass-metal composite properties.

Using the standard vacuum injection technique, glass-reinforced aluminum composites were made using SC-51A aluminum, a casting alloy having high fluidity. These composites had excellent strengths with a high degree of uniformity in tensile strengths, indicating sound castings.

Evaluations of the wetting of several aluminum alloys on glasses formulated to assist in wetting indicated several glasses which were somewhat superior to the standard E glass in present use. Certain glasses were better for certain aluminum alloys.

Preliminary work has begun on development of a glass-reinforced material having utility above 1000°F. Reinforcement of various copper alloys and a large number of inorganic compounds offers promise.

III DISCUSSION

A. Improving existing and investigating new methods of forming and working composites of aluminum and aluminum coated glass fibers.

1. Composites made using aluminum casting alloy having high fluidity.

Using the standard vacuum injection technique,[1] glass-reinforced aluminum composites were made using SC-51A aluminum, a casting alloy having high fluidity. The SC-51A alloy contains 4.5 to 5.5% silicon, 1 to 1.5% copper, .4 to .6% magnesium, .35% zinc, .8% iron, .5% manganese, .25% titanium, .35% nickel, and .5% other elements. Table I presents the tensile strengths of composites made using SC-51A aluminum alloy as the matrix alloy. The composites were not heat treated. The unreinforced SC-51A alloy in the as cast condition has a tensile strength of 24,000 to 28,000 psi. This alloy can normally be heat treated to a tensile strength of 40,000 to 44,000 psi.

TABLE I

GLASS-REINFORCED SC-51A ALUMINUM ALLOY

Sample Number	Tensile Strength at Room Temperature, psi	Average Tensile Strength At Room Temperature, psi
819-81A	24,800	
819-81B	26,300	
819-81C	25,400	
819-81D	24,700	25,700
819-81E	26,500	
819-81F	24,600	
819-81G	27,800	

(1) H. B. Whitehurst - First Annual Progress Report, Contract NOrd 15764

It will be noted in the above table that the tensile strengths are remarkably consistent. A standard deviation of 7% exists in the above figures. The standard glass-reinforced aluminum composite, made using a 14S aluminum alloy, has an average tensile strength of 26,200 psi with a standard deviation of about 25%. Hence, it can be seen that the more fluid casting alloy reinforced with glass fibers in the as cast condition has strengths as good as 14S aluminum reinforced with glass fibers in the heat treated condition. The strengths of the reinforced SC-51A alloy composites are more consistent due to the higher fluidity of the SC-51A alloy and consequent better penetration of the glass fiber bundle.

2. Composites made using elevated casting temperatures.

Using the standard vacuum injection technique, glass fibers were impregnated with molten 14S aluminum at temperatures of 1400 to 1700°F. Previous work has been reported (1 & 2) wherein the molten 14S aluminum was injected at 1100 to 1300°F. This previous study indicated little change in composite with casting temperatures ranging from 1100 to 1300°F. Table II summarizes data taken in the study wherein casting temperatures of 1400 to 1700°F were used.

TABLE II

INVESTIGATION OF ELEVATED CASTING TEMPERATURES

Sample Number	Temp. of Molten Al., °F.	Immersion Time in Molten Al., sec.	Tensile Strength At Room Temp., psi	Avg. Tensile Strength, psi
819-60B	1400	180	39,500	
819-60C	1400	180	28,900	31,100
819-60D	1400	180	25,000	

(1) H.B. Whitehurst and H.B. Ailes-Fifth Quarterly Progress Report, Contract NOrd 15764.

(2) H.B. Whitehurst and H.B. Ailes-Sixth Quarterly Progress Report, Contract NOrd 15764.

Sample Number	Temp. of Molten Al., °F.	Immersion Time in Molten Al., sec.	Tensile Strength At Room Temp., psi	Avg. Tensile Strength, psi
819-61A	1460/1500	150	32,600	
819-61B	1500/1540	120	34,000	33,300
819-61C	1480/1520	150	33,200	
819-62A	1600	120	42,200	
819-62B	1600	120	29,800	35,500
819-62D	1600	120	34,500	
819-64A	1700	75	25,500	
819-64B	1700	75	23,650	25,600
819-64C	1640/1700	120	27,600	

The above data is unusual in that composites formed using molten aluminum temperatures of 1400 to 1600°F had increased composite tensile strengths with increased casting temperatures. However, composites made at 1700°F were weaker than composites made at 1400°F. The higher casting temperatures, which would be expected to decrease the glass fiber strengths, resulted in less time required for penetration of molten metal into the fiber bundle. The shorter casting time (molten metal to glass fiber contact time) may explain the increased composite strengths.

3. Glass micro-balloon reinforcement of aluminum.

Glass micro-balloons of 10 to 250 micron diameter (average diameter of 60 microns) were used in an attempt to reinforce aluminum. Micro-balloons were placed in a pyrex tube, the tube was evacuated and one end immersed in molten aluminum. The molten aluminum flowed up and around the micro-balloons following the walls of the pyrex tube. The aluminum surrounded the micro-balloons, but did not penetrate into the particle bed. If these two materials could be incorporated in some other manner, it might be possible to produce a foamed glass-reinforced aluminum.

B. Determining a complete set of physical data on a standard glass-reinforced aluminum composite in order to indicate the general characteristics of glass-reinforced metals as a class of materials.

1. Composites made by vacuum injection method.

It was deemed advisable to get a relatively complete evaluation of the physical properties of a material which is essentially 14S-T6 aluminum reinforced with 20-30 volume percent continuous longitudinally oriented glass fibers. This material is made by pulling, under vacuum, molten 14S aluminum into a mold containing aluminum coated glass fibers. This material was chosen as the best available one year ago, when the evaluation began. However, since that time, developments have been made which affect the physical properties of glass-metal composites. It has been decided to continue the evaluation of physical properties based on the original composite type so that a related set of physical property data will exist. This set of data can then be used to indicate the properties of materials which incorporate any future developments. The information collected during this reporting period follows:

a. Ultimate compressive strengths

Data on the ultimate compressive strengths of the standard glass-reinforced aluminum composite made by the vacuum injection technique is shown in Table III.

TABLE III

ULTIMATE COMPRESSIVE STRENGTHS

Sample Number	Ultimate Compressional Strength at Room Temp., psi	Average Ultimate Compressional Strength at Room Temperature, psi
EH-XXII-162F-1	132,500	
-2	101,000	
-3	104,000	126,000
-4	125,500	
-5	151,500	
-6	141,000	
EH-XXII-162G-3	138,500	
-4	130,500	132,000
-5	128,500	
-6	129,500	
EH-XXII-162H-1	119,000	
-2	120,500	
-3	120,000	127,000
-4	123,000	
-5	122,500	
-6	155,000	

The above tests were conducted on samples approximately .375 inches in diameter and .750 inches in length. They were tested at a strain rate of .015 inches per minute. Ultimate compressional strength was calculated as the ratio of breaking load to original cross-sectional area.

This ultimate compressional strength data indicates an average ultimate compressional strength for glass-reinforced aluminum of 128,000 psi at room temperature and a maximum of 155,000 psi at room temperature.

Unreinforced 14S aluminum has a compressive yield strength of 60,000 psi at room temperature.

C. Developing a method of forming composites of aluminum and bare glass fibers and evaluating the physical properties of these composites.

1. Wetting Studies.

As reported previously(1) an extensive program was completed evaluating the wetting of 50 different glasses by various aluminum alloys. A statistical evaluation of this program was made. Based on this statistical evaluation, 15 special glasses were produced to represent various predicted wetting characteristics. Eight of these glasses were simple modifications of E glass, two were complex modifications of E glass, one was a refractory glass and two were glasses that were thought to have high solid surface energies. Two other glasses were picked at random.

Wetting tests were conducted by forming fibers of each glass, dipping three of four fibers of each glass in each metal to be evaluated, and then visually examining the dipped fiber under a microscope. The wetting of all the glasses by 2S; 14S; and 5% zinc, 1% cadmium, balance aluminum alloys was evaluated. The 5% zinc, 1% cadmium, balance aluminum alloy wet 12 glasses better than it wet E glass. Six glasses were better than E glass with respect to their ability to be wet by 2S aluminum. 14S aluminum wet one glass better than E glass.

Thus it can be seen that all but four of these glass compositions were as good as E glass for at least two of the aluminum alloys. Two of these

(1) H. B. Ailes - Seventh Quarterly Progress Report, Contract NOrd 15764.

inferior glasses were those picked at random. Thus the statistical study gave 11 out of 13 glasses which were more easily wet than E glass. However, none of these glasses are a large improvement over E glass and further tests must be conducted to establish the significance of the indicated superiority of these glasses to E glass. A general conclusion can be made that certain glasses are better for certain aluminum alloys. It may be possible to tailor-make a glass composition that would be more easily wet by one specific aluminum alloy.

D. <u>Production and testing of glass-reinforced aluminum tubular shapes.</u>

It has been found desirable in the best interest of this project to subcontract to the Olin-Mathieson Chemical Corporation work on fabricating large glass-reinforced aluminum tubes. A detailed description of this work to date is included in Appendix A.

E. <u>Developing a theory on the interaction of metals and glass fibers.</u>

The combination of most metals and glass fibers results in some degradation in the strength of the glass fibers. It is of paramount importance to understand the interaction which takes place between the metal and the glass fibers. Once the interaction is more clearly defined it will, in all likelihood, be possible to control this interaction and produce composite materials of glass and metals having the most desirable properties. Figure IX (Appendix B) plots the room temperature tensile strength of metal coated fibers versus the temperature at which the metal was applied to the fibers. This figure indicates the effect of the temperature at which an alloy is applied to a single glass filament on the tensile strength of the coated filament. The alloys shown in this figure represent the best coating alloys known to date and cover the range from reactive to non-reactive metals. Figure IX shows there is a definite decrease in coated fiber tensile strength with increased metal application temperature.

It will be noted that for lead and zinc coatings there is a small initial increase in coated fiber strength as the coating temperature is increased. This might be explained as a result of viscosity changes in the metal alloy allowing less metal to be applied to the filament as the metal application temperature is increased. Less metal may cause less fiber strength degradation.

Figure IX does not definitely indicate whether the fiber strength degradation is due to chemical, thermal, or mechanical reaction of the metal upon the fiber. The issue is clouded since it is quite likely that both of the postulated chemical and mechanical effects of metal upon the fiber are temperature dependent.

F. <u>Developing a glass-reinforced metal having utility at temperatures above 1000°F.</u> Composites have been made by hot pressing glass fibers coated with aluminum-copper alloys. It is hoped that these composites would have better tensile strengths at 1000°F than the composites made by hot pressing aluminum coated glass fibers. Composites were made by hot pressing glass fibers coated with a 5% copper, balance aluminum alloy. In general, the glass fibers used to make these materials were not too satisfactory since the application of the copper-aluminum alloy resulted in a rather brittle coated fiber. It was impossible to apply aluminum-copper alloys having high copper concentrations. A 33% copper, balance aluminum alloy made fibers which were too brittle to handle.

It has been decided to reroute efforts to the brass alloys. In general these copper-zinc alloys have lower melting points than the copper-aluminum alloys and may very well have good high temperature strengths.

Composites have been made by reinforcing combinations of cupric and cuprous chloride. This material had a metallic appearance, appeared to be somewhat ductile and quite tough. It is thought that it will be possible to reinforce many inorganic compounds with glass fibers. These materials may have utility at high temperatures.

A new glass has been obtained which can be formed in existing equipment but has a softening range about 400°F higher than E glass. This glass should allow the use of metals having higher melting points. It is hoped that it will be possible to reinforce copper-nickel alloys.

IV FUTURE WORK

The expiration date of this contract is October 31, 1957. Negotiations have been opened with the Navy Bureau of Ordnance to extend this contract for one year. Subject to Navy Bureau of Ordnance approval work during the next quarter will be in this direction.

Olin-Mathieson will attempt to scale up the vacuum injection procedure used in the OCF laboratory to produce 1 inch diameter glass-reinforced aluminum tubes. Olin-Mathieson will produce by this method and test in internal bursting 6 inch diameter tubes. Work will continue on centrifugal casting and vacuum-pressure casting equipment in order to produce large glass-reinforced aluminum shapes by these methods.

A detailed study of the aluminum-glass fiber interaction will be continued with the improvement of room temperature strengths of glass-reinforced aluminum as a target. Attempts will be made to protect the fibers from reaction with the molten aluminum in order to evaluate the effect of chemical interaction. Vacuum plating of metals on glass fibers will aid evaluation of the thermal interaction. Half-coating fibers with metal should shed some light on the mechanical interaction of the metal and the glass fibers.

Efforts will be directed toward development of a theory explaining the formation and behavior of glass and metal combinations.

Various inorganic compounds will be reinforced with glass fiber in an attempt to make a glass-reinforced material having utility above 1000°F. High softening point glasses and copper alloys will also be combined in this development.

Additional results will be available on physical properties of glass-reinforced aluminum composites. Modulus of elasticity in shear, compressive strength, creep rate, stress rupture characteristics, and fatigue strengths will be measured at temperatures up to 1000°F. The water absorptive capacity and wet strength of glass-reinforced aluminum will be measured.

Work will continue on developing improved glass-reinforced aluminum materials. The optimum conditions will be determined for forming composites by hot pressing aluminum coated glass fibers. Preliminary experiments will be conducted on the extrusion of glass-reinforced aluminum.

V APPENDIX A

PRODUCTION OF LARGE GLASS REINFORCED ALUMINUM CYLINDERS

COVERING PERIOD NOVEMBER 1, 1956 to SEPTEMBER 15, 1957

SUBCONTRACT UNDER NOrd 15764

by

WARREN H. KAYE
METAL-GLASS RESEARCH SECTION
GLASS, METALS AND PLASTICS DEPARTMENT

SEPTEMBER 23, 1957

OLIN MATHIESON CHEMICAL CORPORATION
Research Laboratories
New Haven, Connecticut

TABLE OF CONTENTS

I. INTRODUCTION

Olin Mathieson Chemical Corporation (OMCC) is a subcontractor to Owens-Corning Fiberglas Corporation (OCF) under contract NOrd 15764 for the purpose of producing and testing large glass-reinforced aluminum cylinders, and making physical property measurements of experimental OCF glass-reinforced aluminum samples. The contract reads as follows:

> "Work under this subcontract shall be devoted to fabrication of large shapes, particularly tubing, of glass reinforced aluminum and testing of glass-metals samples. It is understood that OMCC has available the knowledge and facilities for metallurgical process development. Considerable heavy-duty metal-working equipment can be made available."

The subcontract was issued effective November 1, 1956 through November 1, 1957. This report is written to cover activity from inception of the program to September 15, 1957.

The major efforts during this period have been:

A. Designing and building centrifugal casting machines, developing casting techniques.

B. Product evaluation.

C. Investigating effects of process variables on quality of castings.

D. Investigating effects of materials and process characteristics on quality of castings.

E. Investigating methods of treating Fiberglas preform to improve physical and physico-chemical characteristics.

F. Designing and building apparatus for vacuum-pressure impregnation of Fiberglas forms.

G. Physical testing OCF samples.

The work reported represents the combined efforts of the personnel of the Metal-Glass Section of the Glass, Metals and Plastics Department headed by Mr. Meade McArdle. Acknowledgement is also made of the valuable assistance given by members of the Plastics Research Section under Dr. Leo S. Burnett, Chief.

II SUMMARY

The principal objective of this project is to fabricate glass-reinforced aluminum tubes of nominal dimensions, 12 to 24 inches long, 6 to 8 inches O.D., 1/4 to 1/2 inch wall, which will be suitable for bursting strength tests in substantially the as cast condition and dimensions. Centrifugal casting appeared to be the most promising method based on limited experiments by OCF using preforms of aluminum coated glass fibers helically wound on an aluminum screen mandrel.

Until late February, 1957, therefore, OMCC was engaged in designing, building, purchasing and installing equipment in a new laboratory area in New Haven, Connecticut, for melting, casting and heat treating aluminum, and for the centrifugal casting of glass-reinforced aluminum tubes. Provisions were made for recording critical process temperatures with an 8-point recording potentiometer pyrometer. The present laboratory facilities, devoted almost exclusively to work on this subcontract, are shown in Figure I.

A 150 ton hydraulic press, #19 and #20 Bliss presses, large Porter-Johnson shaper, Stokes vacuum pump, physical chemistry lab, and physical testing facilities are now available in addition to a larger and improved centrifugal casting machine and new vacuum impregnation units built in the New Haven shops.

The first casting was made in a sand-lined 6 inch diameter iron flask on February 27, 1957. A total of 35 glass-reinforced aluminum castings was made in this machine. It was then converted to accommodate a permanent mold of stainless steel, 7.7 inches I.D., for higher speed operation at elevated temperatures.

Forty-two castings have been made since June 7, 1957, in the present machine -

a total of 77 experimental runs to date. Detailed experimental data are presented in Table I and product evaluation in Table II. The present centrifugal casting machine and an array of cast tubes are shown in Figure II. The tubes are shown in sequence from left to right, rear to front.

Investigations have been made into the effects on casting quality of the process variables, materials characteristics and process dynamics. Over a wide range of experimental conditions, the interdependent relationships between certain of these factors have precluded the attainment of wholly satisfactory cast tubes, and laboratory work has been undertaken concurrently with centrifugal casting experiments to devise ways and means of overcoming weaknesses in materials and eliminating or modifying undesirable process dynamics. The results of this work have been encouraging enough to warrant further efforts in this direction.

An alternate method of compositing aluminum and Fiberglas in various forms has been developed involving the vacuum-pressure impregnation of various preform Fiberglas shapes, including cylinders and cones. Assembly of this apparatus has just recently been completed, and the unit has tested out satisfactorily so that experimental work is now underway.

The physical strength properties of 196 glass-reinforced aluminum samples submitted by OCF have been determined in our laboratories at both room and elevated temperatures. These tests have included determination of tensile strength, elongation, modulus of elasticity in tension, ultimate compressive strength and modulus of elasticity in compression.

III DISCUSSION

A. Centrifugal Casting Machine Design and Casting Techniques.

1. Construction and use of 6 inch casting machine.

Bolted steel structural members were used for the basic framework of the machine so that it could easily be modified to accommodate cylindrical molds up to 10 inches diameter by 3 feet long. The first mold was carbon steel 8 3/16 inches I.D. x 12 11/16 inches long, driven directly by a 1 HP motor through a Lewellen chain drive with a range of 275 to 1800 rpm. The direct drive soon presented an alignment problem which was eliminated by changing to belt driven rolls. Sand liners, either resin or CO_2 bonded, were necessary in this steel mold so as to insulate it sufficiently from the preform preheating element and the molten metal to permit high speed operation without exceeding a safe working stress. Preparation of satisfactory resin bonded liners proved difficult and time consuming, and a relatively new technique was applied by using CO_2 bonded sand liners formed and cured directly in the flask around a centralising core. Fiberglas preforms universally wound on a 6 inch diameter screen support were encased in various shell materials (such as stovepipe) to eliminate the coarse, irregular surface resulting when the metal was cast against the rawsand liner. In this fashion, the encased preform could be used as the centralising core. Best results were obtained with a heavy wall, iron pipe core, lighter weight materials proving unsatisfactory because of seaming and buckling under heat and pressure. Centrifugal forces of 7 to 445 gravities were employed in this machine, developing radial pressures up to 11 psi for a 1/4 inch wall casting.

The first pouring trough (for charging molten metal to the rotating casting chamber) used was the "end pour" type. It was a rectangular block of graphite bored with a 1 inch hole widening into a shallow funnel at one end. The trough was heated on three sides along its length with externally mounted, powerstat controlled calrods to maintain fluidity of the cast metal. The trough and heater assembly was mounted on a track and could be traversed in and out of the spinning mold with a hand crank. This arrangement also allowed the calrod heaters to supply radiant heat to the Fiberglas preform before casting. Also mounted on the track in pouring position was a frame supporting the hand shank and graphite crucible containing the alloy melt. Pouring with this type trough has the disadvantages of rapidly developing high shear and compressive forces as well as making it more difficult to obtain even metal distribution. However, it is believed that air and other gases are not as likely to be entrapped within the cast tube, but are swept to the mold ends where they can easily escape.

A heated graphite box trough with a bottom pour slot was tried without success since even distribution could not be achieved. The slot was then plugged and the trough mounted on a rotatable shaft so that the molten metal could overflow in a thin stream along the entire length. This method was abandoned because the geometry of the mold, end flanges and trough severely limited the volume of metal which could be cast in one shot.

Refinements of the end pour technique followed with the addition of a gear motor to drive the track, and a cam follower-guide rail device to tilt the crucible at a predetermined rate to obtain an even distribution of cast metal. It was necessary to put aside the latter device temporarily because of the necessity for laborious recalibration in each succeeding experiment to conform to the increased or decreased metal shot required by the use of various dimension Fiberglas preforms. Good results were obtained in most cases with this device, however, and warrant its use on the present machine as soon as a standard dimension preform is used.

A total of 35 castings was made in this machine before it was converted to accommodate a longer stainless steel permanent mold. Pertinent data are recorded on page 1 of Table I (Appendix A). A picture of this machine is carried in an earlier report.(1)

2. <u>Construction and use of 8 inch casting machine.</u>

A heavy wall stainless steel (type 304) mold, 7.7 inches I.D. x 36 inches long was fabricated and installed in the modified base, together with a 3 HP Varidrive motor. These modifications permit casting longer tubes directly into the mold at higher rpm and higher temperatures. A draft of .020 inch/foot was provided to facilitate removal of the finished castings. This high-strength mold eliminated the need for sand liners and inserts which would become increasingly more difficult to assemble for longer castings. Centrifugal force was made available through a range of 7-1200 gravities at from 250 to 3362 rpm. Radial pressures up to 30 psi for 1/4 inch wall castings, 60 psi for 1/2 inch wall castings and 74 psi

---

(1) H. B. Ailes - Second Annual Progress Report, Contract NOrd 15764.

for a 5/8 inch wall casting were attainable.

The use of heavier shafts, self-aligning bearings, central guide rollers, hold-down safety rollers and A-belt drive resulted in smoother operation with less vibration. A longer graphite tube feeder and pour box were fabricated for casting tubes up to 20 inches long, the maximum length of preform that OCF could wind. It became necessary then to wind preforms to 7.7 inch O.D. specification. A split bulkhead ring is inserted in the flask to permit casting tubes shorter than the 36" flask length.

External gas burners were installed to preheat the flask, an internal gas fired radiant tube or open gas flame is used to preheat the Fiberglas preform in place. The trough is preheated in an electric furnace prior to casting.

A picture of the present machine is shown in Figure II, below an array of 77 glass-reinforced aluminum cast tubes made in this and the previous unit. Pertinent data on the 42 castings made in the present unit are carried on the second and third pages of Table I (Appendix A). Some of these runs were necessarily made with glass forms other than universally wound cylinders, when our supply of these was temporarily exhausted. For the same reason a few castings were made with some overruns of smaller universally wound preforms by encasing them in heavy wrappings of asbestos, etc., to fit the larger flask.

B. Product Evaluation.

All castings so far have had obvious physical defects which made them unsuitable for physical testing in their as cast state. Sound sections were generally too short to avoid major end effects in burst strength tests. In addition, wide variations in wall thickness made it impractical to turn down the tubes on a lathe. Whenever this was done, hidden defects were uncovered.

The evaluation of the cast tube products so far has been necessarily qualitative rather than quantitative, since no physical test data are yet available. However, much was learned concerning the apparent effects of process variables, materials characteristics and process mechanics through a careful scrutiny of the castings and microscopic examination of transverse and longitudinal sections cut from them.

Product evaluation data are presented in Table II (Appendix A) and are largely self-explanatory with the aid of photograph references.

C. Effects of Process Variables on Quality of Castings.

1. Preheating flask and/or glass preform.

OCF has observed that the initial (2-3 minute) tensile strength of E glass fibers decreases with temperature from 475,000 psi at room temperature to 175,000 psi at 1200°F., most of the strength loss occurring above 500°F. Excessive fiber embrittlement has been observed in each casting experiment involving the preheating of the glass, since this takes considerable time. Then, too, metal casting temperatures up to 1500°F are involved and the castings have not been rapidly chilled. This could be done with a water spray on the mold, assuming complete penetration to the mold wall is achieved. Concurrent laboratory experiments do indicate that heating glass fiber structures to 1000°F or over facilitates metal coating but does not materially assist penetration. Centrifugal casting results are seemingly just as good without preheating the glass, but there is no physical data yet to substantiate this observation.

Warming the mold to 300° to 400°F has been found helpful in assisting penetration and avoiding cold shuts. Higher temperatures result in difficult extraction of the casting from the mold.

2. Bare fibers versus aluminum coated fibers.

It was found in early experiments that the aluminum coating on smaller diameter fibers (.4 mil diameter) oxidized excessively during preheat and penetration of the fibers was poor. Larger diameter bare fibers (1-2 mil diameter) were penetrated more successfully in later experiments. It is believed that an evaluation of 1-2 mil aluminum coated fibers without preheat would be helpful in establishing definitely whether the fiber spacing effect can contribute to better casting quality.

3. Fiber diameters, thicknesses and weights of preform.

Fibers between 1 and 2 mil diameters apparently yield optimum results, larger diameters becoming too brittle to handle, smaller diameters offering more resistance to penetration by molten aluminum. It is very important that winding thickness, number of strands wound simultaneously, number of ends in strand, fiber diameters, bulk density and O.D. be standardized as much as possible from now on so that the effect of other process variables can be more clearly delineated. It is suggested that preforms be wound as tightly as practicable on a rigid shipping tube which can be easily removed once placed in the mold. The O.D. of the winding should be such that the preform fits snugly in the 7.7 inch I.D. flask. Windings of .001 to .0015 inch diameter bare fibers should be established as standard until changes in these specifications are warranted by experimental results. Actually, much more thickly wound preforms have been used with considerable difficulty in preparation for casting (casting #60, 2067 gms. glass). The middle preform in Figure V illustrates an approach to the kind of structural integrity desired, compared with the two shown with heavier windings.

The fibers in some cases should also be coated in forming with a layer of a specific aluminum alloy so that the value of this technique may be determined under controlled experimental conditions.

4. Glass types.

The results of experiments with glass forms other than universally wound continuous fiber preforms have been disappointing and indicate that the latter still may be considered the most suitable preform structure for centrifugal casting of tubular shapes. The other forms investigated have a much lower bulk density, are more highly compressible, resulting in poor distribution of fibers in the composite. Fiberglas fabrics and screening are not under serious consideration because of low glass loading, extreme resistance to fiber penetration, etc. Casting Nos. 69 and 71, Figure IV, are examples of tubes incorporating fabric and screen, respectively. Because of the extremely open weave of the screen, good penetration was achieved (but not into the strands) in No. 71, and a fairly regular 24" casting was obtained which may be worthwhile testing for bursting strength. The heavy polyvinyl chloride coating on the strands was not removed prior to casting, so that advantage could be taken of the spacer effect. Most of this coating burned off during casting, but released objectionable HCl vapors.

5. Internal preform supports.

Light gage screen materials (see aluminum screening in Figure V) are not rigid enough for long heavy windings, and heavier materials tend to run eccentrically in the machine. All such supports offer additional resistance to radial flow of cast metal, absorb heat from the aluminum in melting, and introduce oxide films which are undesirable. Much better results are obtained when the fiber structure has enough integrity to permit removal of the internal support before casting.

6. External wraps, surface characteristics.

A single wrap of Coromat or expanded aluminum screen (Figure V shows expanded aluminum screen) around a universal preform provides a thin insulating layer of low density which enables more metal to flow through the outermost strands of the preform fibers before freezing off at the mold wall. A somewhat smoother outside surface may be attainable by this technique which has not yet been fully explored. Figure IV, No. 52, illustrates the matte surface obtained in some areas with one Coromat outside layer which itself was not penetrated but was brushed off after casting. Expanded aluminum screen may prove to be even more effective in this respect.

7. Centrifugal force.

The weight of aluminum cast is calculated to fill an estimated 90% voids within the Fiberglas preform structure as supplied by OCF; the more glass, the more aluminum required to fill the voids. Centrifugal force, expressed in Gravities, varies directly with the radius of the mold and the square of the mold rpm, being independent of the amount of metal cast. Radial pressures developed in the molten metal depend not only on the rpm but on the wall thickness of the casting before the metal freezes. Since complete penetration has not been achieved with radial pressures up to 30 psi for 1/4 inch wall castings (60 psi - 1/2 inch wall; 72 psi - 5/8 inch wall), it may be desirable to pour a metal shot considerably in excess of the theoretical amount required to form a finished casting. Thus, higher radial pressures can be applied without rebuilding the machine to achieve higher mold speeds. This procedure is contemplated in the Future Work section of this report.

8. Aluminum alloys, etc.

Tensaloy, a nominal 8% zinc, 0.4% magnesium, 0.8% copper, balance aluminum, alloy was used in the earlier castings because it has good strength properties and is an age hardening alloy not requiring heat treatment subsequent to casting. Such treatment was known to cause severe warping in vacuum injected glass-reinforced aluminum rods made in the OCF labs. However, the foundry characteristics (fluidity, resistance to hot cracking, and pressure tightness of castings) of Tensaloy were not compatible with the centrifugal casting process. An alloy possessing better characteristics was sought and found in SC51A (nominal 5% silicon, 1% copper, balance aluminum alloy). Alloy S5A (5% silicon, balance aluminum) was selected as an alternate material. Alloy SC51A gave much better results than

Tenzaloy or even S5A, and was established as the temporary standard for most of the casting experiments in the present machine. OCF was asked to evaluate this alloy in their vacuum injection process for making 0.45 inch diameter rods with longitudinally oriented fibers. A recent report on physical tests of a series of such samples indicates an average tensile strength of 25,700 psi at room temperature. In effect, the SC51A alloy produced a composite as strong as those made with the 14S-T6 alloy upon which OCF's best data had been obtained previously. It is further noted that the SC51A composites were not heat treated (therefore, not warped) before testing; the 14S composites were. SC51A is normally heat treated, however, to develop maximum strength, and significant improvement can be expected in tensile strength of glass-reinforced aluminum if warping can be held to a minimum during heat treatment. The tensile strength of seven SC51A composites tested had a standard deviation of only 7% indicating remarkably consistent results for composites of this type.

2S aluminum and alloys 14S, 32S, 2S containing 1% cadmium, 1 1/2% zinc, and 32S containing 7.36% zinc were cast in an attempt to correlate results with OCF data obtained with these alloys. Results were, in general, unsatisfactory.

It is good foundry practice to hold pouring temperatures within 50° to 75°F of the melting point. However, the compositing process requires more heat content to maintain the fluidity of the metal long enough to penetrate the glass fibers. Therefore, metal pouring temperatures were increased up to 1500°F for the most part. This limit was established to avoid excessive oxidation and absorption of gases leading to porosity, inclusions and defects in casting. It is contemplated, however, that more superheat may be required to maintain liquidus temperatures in the spinning mold until complete penetration of the Fiberglas preform is achieved. (See Future Work section). Added precautions must then be taken to maintain metal purity.

D. Effects of Materials and Process Characteristics on Quality of Castings.

1. Fiberglas preforms.

It was found that several characteristics of the preforms used have prevented the attainment of good castings:

a. Bare glass is not wet by molten aluminum, strands resist penetration.
b. Glass fibers are embrittled by time-at-temperature, and weakened by rubbing in contact with each other.
c. Helically wound glass forms are of low bulk density, thus are highly compressible by centrifugal force and radial pressures developed in the molten metal. Strands tend to migrate during casting and the compressed fibers strongly resist penetration by molten aluminum.
d. A loose helical wind gives rise to longitudinal contraction of preform at high rpm, allowing cast metal to flow around ends of preform, creating back pressure which results in bunching of strands, uneven wall thickness, poor penetration.
e. Loose construction, lack of ridigity, and variable O.D., introduce handling problems in preparation for casting. Attempts to overcome these and associated deficiencies are discussed in E. below.

2. <u>Process dynamics.</u>

a. Only moderate radial pressure is developed at speeds of 3400 rpm because only thin wall castings of a light metal, aluminum, are being attempted. However, this pressure is developed almost instantaneously with impacting force, which compresses the glass fibers unevenly.

b. Considerable shear forces are developed as the cast metal is rapidly accelerated to the rpm of the flask. These forces tear the glass fibers and distort the preform geometry.

Pressure modifications designed to overcome these limitations are contemplated under the Future Work section.

E. <u>Modification of Fiberglas Preform to Improve Physical, and Physico-Chemical Characteristics.</u>

To alleviate some of the Fiberglas preform weaknesses noted in D. above, it was undertaken to find active agents with which preforms could be treated to:

1. Enhance wettability of the fibers, thus assisting penetration and resulting in better bond strength. Because a molten metal possesses a high free surface energy, it has a high angle of contact (or low work of adhesion) on a glass surface and will not wet it. Exploratory experiments have been conducted in the laboratory with the object of overcoming this difficulty by coating glass fibers with organic, inorganic and metal-organic salts to reduce interfacial tension at the instant of contact with the molten metal. In every trial where a metal-organic was applied to glass fibers, molten aluminum coated them. Erratic and unpredictable results were obtained

with inorganic salts. Oxide coatings of lead, titanium and barium produced an unwettable surface. Experiments with TiC are continuing on the basis of reports indicating that its high free surface energy is effective in rendering various surfaces wettable by molten aluminum. Although OCF experiments indicate that precoating fibers with aluminum in the forming process is helpful in promoting penetration and wettability, these effects have not been observable in centrifugal casting work.

2. Protect glass fibers from degrading effects of heat and abrasion with a coating which also spaces the individual fibers apart to assist penetration. The coating must be effective in very thin layers, be volatilized completely by the cast metal, or be innocuous to the metal matrix by alloying effictively with it. A coating of this nature would best be applied at the time of forming the fibers. An aluminum coating serves as a protective layer, but it is believed that an oxide film on the greatly extended surface precluded effective wetting and penetration in the centrifugal casting experiments.

Various organic coatings which also rigidized the preform were tried without success. Such a dual-purpose coating would eliminate the need for internal screen supports, minimize migration of fibers, result in more uniform fiber distribution, and make preforms easier to handle in process.

A solution of styrene resin was applied to a preform which became somewhat rigid when dried, and molten aluminum was cast into it (Figure IV, No. 51). Although most of the resin was burned off as it came in contact with the molten aluminum, penetration was not improved. Some strands were bonded together and not penetrated at all (see Figure IV, No. 51). Similar results were obtained with polymethylmethacrylate, ethyl cellulose, sodium silicate, and polyvinyl chloride.

F. <u>Design and Construction of Apparatus for Vacuum-Pressure Impregnation of Fiberglas Forms.</u>

This apparatus provides for the vacuum removal of entrapped air in the preform, and takes advantage of the fact that contact angles between a solid and liquid are lower in a vacuum than in air. The disadvantages of centrifugal casting process dynamics are eliminated and a uniform distribution of gradually applied forces is achieved with atmospheric or higher nitrogen pressures. Oxidation of fiber coatings and molten aluminum is held at a minimum. The ability to preheat the Fiberglas in vacuo is also an advantage.

Essentially, the unit consists of a vacuum chamber containing a graphite melting pot on a hot plate imbedded in refractory sand and surrounded by a closely fitting refractory cylinder in which are imbedded heating coils of ni-chrome wire. Between the pot and the vacuum tank is a reflecting shield of brass which has been chrome plated on the inside surface and is fitted with a cover containing a trap door operated by two rods extending through the side wall of the chamber. This shield prevents the tank from becoming heated to unsafe temperatures under applied vacuum or pressure as well as permitting some control of the preheating of the Fiberglas preform. The preform is suspended above the shield on a holding device mounted on a rod which passes through a bushing at the top of the tank. Temperatures at six critical points are continuously recorded by a recording potentiometer pyrometer. Power leads and thermo-couple wires are sealed into the tank wall through two separate plastic bushings. Provisions have been made for pressurizing the vessel with nitrogen while the preform is submerged under the surface of the molten aluminum, to aid in full penetration of the fibers.

G. Physical Testing of OCF Samples.

A Tinius Olsen plastiversal machine which was available in the plastics section of the Glass, Metals and Plastics Department was provided with the accessories required for room temperature and elevated temperature testing of glass-reinforced aluminum samples. These accessories included a Foxboro controller for a 16 inch Marshall furnace, an S2 type extensometer and transfer mechanism, and a set of V-jaw grips and threaded and specimen holders. The temperature range of the furnace permits testing of specimens up to 1800°F. This equipment is shown in Figure I. The testing machine was already equipped with compression plates and a stress-strain recorder.

The physical strength properties of 196 glass-reinforced aluminum samples submitted by OCF have been determined in our laboratories at both room and elevated temperatures. These tests have included determination of tensile strength, elongation, modulus of elasticity in tension, ultimate compressive strength and modulus of elasticity in compression.

IV FUTURE WORK

A. Modification of centrifugal casting design and techniques will be continued with the purpose of minimising the very high shear and compressive forces involved in casting molten metal into the Fiberglas preform at high mold speeds. This may be accomplished by:

1. Providing an auxiliary low speed drive which will enable casting the whole shot at minimum retention speeds as low as 110 rpm; then increasing the speed gradually with the main drive to develop maximum centrifugal force. "Pumping" action of the molten metal at the low speeds should also assist in penetration of the preform under conditions of minimum radial pressure. Increased contact time between the molten metal and glass fibers before freezing begins at the mold wall is expected to improve wetting of fibers; and/or

2. Using a screen-type or turbine-type accelerator built into the centrifugal casting mold to accelerate the cast metal tangentially to the circumference of the mold and thus materially reduce shearing action.

3. In conjunction with the above, a double or triple shot of molten aluminum may be cast at one time to multiply the radial pressure developed at maximum machine speeds as well as to gain the advantages of the additional heat content of the extra-metal. In this case, a melt-out bulkhead could be provided at one end of the mold which would allow the bulk of the excess metal to overflow at a predetermined time into a reservoir and be recovered therefrom. This would eliminate the necessity for extensive machining operations to produce a finished casting.

B. Laboratory investigations will be carried on to find surface active agents or other treatments of the Fiberglas materials which will perform one or more of the following functions:

1. Increase the wettability of the fibers. A variation of the nature of the glass has been discarded as relatively unimportant. But it is strongly felt that fluorine in, or chemical treatment of, the glass surface by non-aqueous vapors of halides, particularly fluorides and/or chlorides of silicon, germanium, tin, lead, aluminum, boron and similarly electro-negative elements would give improved bonding without vigorously attacking the glass. Perhaps even gaseous chlorine would be effective, but in any event a chlorinated surface is expected to be an improvement, especially if chlorine can be connected to silicon. It is also thought that treatment of the glass with a borane might be productive of a more wettable boron skin.

2. Act as a fiber spacer to assist penetration of the molten metal, and

3. Temporarily rigidize the preform shape to facilitate handling, impart dimensional stability, and eliminate the need for inner support screens as well as the tendency of helically wound fibers to contract longitudinally when spun at high speeds.

It is believed that either plastic or metal coatings can be applied which will perform more than one of these functions simultaneously.

C. An alternate compositing method based on the vacuum injection of aluminum into Fiberglas universally wound on a mandrel is now being investigated. The

The procedure is based on the results of OCF's laboratory experiments by which they produced a 1 inch tube which when tested exhibited satisfactory rim strengths.

The OCF Glass-Metals Research Laboratory will supply strands of aluminum coated fibers to the Ashton, Rhode Island Textile Division labs, where a tight helical winding of these fibers will be applied on an 18 inch long steel mandrel, 5 inches in diameter, supplied by OMCC. This mandrel is a length of 1015 steel pipe, specially case hardened and fitted to the standard 2 inch winding mandrel used in the Ashton lab. The pipe mandrel carrying the glass winding will then be inserted snugly into a length of 6 inch diameter case hardened steel pipe having a 1/4 inch wall and a 5 1/2 inch I.D. A flange containing a vacuum connection will then be welded to one end of the assembly so as to seal completely the annular space. This unit will then be heated by combustion gases over an aluminum melting furnace, the open end then submerged in the molten aluminum and full vacuum gradually applied so that atmospheric pressure will inject the molten aluminum into the glass preform.

D. Bursting strength tests and other physical measurements will be conducted on suitable tubular products. An apparatus for determining the bursting strength of 7.7 inch O.D. glass-reinforced aluminum tubes has already been designed and bids have been requested for its fabrication. The rim strengths of the glass-reinforced aluminum composites will be calculated from bursting strength data obtained with this apparatus.

E. Vacuum-pressure impregnation techniques will be investigated with both cylindrical and dish-shape Fiberglas preforms, using the apparatus shown in

Figure VIII and previously described.

F. Physical testing of OCF glass-reinforced aluminum samples will be continued as required.

TABLE I

Cast. No.	Type of Glass	Fiber Dia. Mils	Glass Wgt. Gms.	Preform Wrapped In	No. of Ends	Screen Type, Inner	Type of Metal
A-1	Al.Coat.Fib.Pref.No. 1	.4	191	Asbestos	1-2	Al, 18x14	Tenzaloy
R-2	" " " " No. 3	.4	181	Reynolds Wrap	1-2	"	"
R-3	" " " " No. 4	.4	184	"	1-2	"	"
R-4	None	--	None	None	--	None	"
1	Al.Coat.Fib.Pref.No. 6	.4	181	"	1-2	Al, 18x14	"
2	" " " " No. 7	.4	227	"	1-2	"	"
3	Bare Fiber Pref. No.12	.4	205	"	4-6	"	"
4	Flexible Filter Mat	1.25	--	Chef. Foil	--	"	"
5	Bare Fiber Pref. No.13	.4	205	.0095 Tin Plate	4-6	"	Alcoa 14
6	Flexible Filter Mat	1.25	96	"	--	"	"
7	Bare Fiber Pref. No.14	.4	182	"	4-6	"	Alcoa 32
8	Flexible Filter Mat	1.25	119	"	--	None	"
9	Flexible Filter Mat	1.25	60	"	--	Al, 18x14	Alcoa 2S
10	Bare Fiber Pref. No.43	3	238	"	1	"	Tenzaloy
11	" " " No.44	3	238	Stove Pipe	1	"	"
12	K75 Flocking	--	145	Al. Foil	--	1[illegible] ga. 2 mesh Steel	"
13	Bare Fiber Pref. No.37	2	233	Stove Pipe	1	Al, 18x14	Tenzaloy/A
14	" " " No.38	2	296	"	1	"	"
15	Flexible Filter Mat	1.25	90	"	--	19 ga. 3 mesh Copper	"
16	Bare Fiber Pref. No.40	2	225	20 ga. S.S.	1	Al, 18x14	"
17	" " " No.42	2	304	Stove Pipe	1	"	"
18	Flexible Filter Mat	1.25	120	"	--	"	"
19	Bare Fiber Pref. No.39	2	277	"	1	"	"
20	" " " No.36	2	243	Iron Pipe	1	"	"
21	Al.Coat.Fib.Pref.No. 9	.4	199	"	1-2	"	"
22	" " " " No. 8	.4	206	"	1-2	"	Alcoa 2
23	Bare Fiber Pref. No.41	2	275	"	1	"	"
24	Al.Coat.Fib.Pref.No.10	.4	190	"	1-2	"	Alcoa 2S 1100, 1.
25	Bare Fiber Pref. No.28	1	271	"	1	"	"
26	Al.Coat.Fib.Pref.No.11	.4	202	"	1-2	"	"
27	" " " " No.26	.4	219	"	3	"	"
28	Bare Fiber Pref. No.27	1	289	"	2	"	SC51A
29	" " " No.32	1	268	"	2	"	55A
30	Al.Coat.Fib.Pref.No.25	.4	221	"	3	"	SC51A
31	Bare Fiber Pref. No.54	2	226	"	2	"	"

TABLE I

Preform Wrapped In	No. of Ends	Screen Type, Inner	Type of Metal	Metal Wgt. Gms.	Flask Heater Type	Trough Type	Feed* Type	Temp. °F at Pour: Flask O.D.	Temp. °F at Pour: Glass	Temp. °F at Pour: Metal	RPM	Cast. Wgt. Gms.
bestos	1-2	Al, 18x14	Tenzaloy	2270	Calrod I.D.	End Pour	MRF		1600	1200	1750	1660
ynolds Wrap	1-2	"	"	3178	"	"	MRF		1350	1350	800	3270
"	1-2	"	"	4540	"	"	MRF		1350	1450	300	3060
ne	--	None	"	4540	"	Bot. Slot.	MRF		1080	1600	400	3690
"	1-2	Al, 18x14	"	5537	"	"	MRF		1200+	1200	300	3138
"	1-2	"	"	4539	"	"	MRF		800	1500+	350	2710
"	4-6	"	"	4539	"	"	MRF		800	1400+	1000	4770
ef. Foil	--	"	"	5448	None	"	MRF	Room	Room	1397	1750	5500
05 Tin Plate	4-6	"	Alcoa 14S	7150	"	"	MRF	Room	Room	1465	1750	6440
"	--	"	"	4994	"	"	MRF	Room	Room	1385	1750	4900
"	4-6	"	Alcoa 32S	2280	"	Tilting	MC	Room	Room	1462	275	2442
"	--	None	"	2300	Calrod I.D.	"	MC		100	1500	232	2320
"	--	Al, 18x14	Alcoa 2S	2307	"	"	MC		1450	1450	800	2494
"	1	"	Tenzaloy	2500	"	"	MC		100	1460	282	1840
ove Pipe	1	"	"	2500	None	"	MC	Room	Room	1455	1570	2680
. Foil	--	19 ... 2 mesh Steel	"	2500	"	"	MC	Room	Room	1500+	1415	3075
ove Pipe	1	Al, 18x14	Tenzaloy/5%Cd	3000	"	"	MC	Room	Room	1450	1310	2985
"	1	"	"	4540	"	End Pour	M	Room	Room	1400	1535	4515
"	--	19 ... 3 mesh Copper	"	4540	"	Tilting	MC	Room	Room	1385	1200	2815
ga. S.S.	1	Al, 18x14	"	4540	"	End Pour	M	Room	Room	1485	1465	4520
ove Pipe	1	"	"	4540	"	"	M	Room	Room	1465	1360	4700
"	--	"	"	4540	"	"	M	Room	Room	1370	1415	4300
"	1	"	"	4540	"	"	M	Room	Room	1270	970	4620
on Pipe	1	"	"	4540	"	"	M	Room	Room	1450	1865	4425
"	1-2	"	"	4540	Calrod I.D.	"	M		480	1350	1780	4350
"	1-2	"	Alcoa 2S	[illegible]	None	Tilting	MC	Room	Room	1500	1715	2650
"	1	"	"	2632	"	"	MC	Room	Room	1500	1465	2450
"	1-2	"	Alcoa 2S with 1%Cd, 1.5%Zn	2700	"	End Pour	A	Room	Room	1450	1800	2820
"	1	"	"	3200	"	"	A	Room	Room	1450	1810	3430
"	1-2	"	"	2200	Calrod I.D.	"	A		520	1500	1740	3075
"	3	"	"	3200	"	"	A		820	1500	1765	2810
"	2	"	SC51A	3200	"	"	A		750	1500+	2200	3324
"	2	"	S5A	3200	"	"	A		750	1500	2008	3444
"	3	"	SC51A	3200	"	"	A		910	1500	785	3300
"	2	"	"	3200	None	"	A	Room	Room	1425	1622	3320

Comb. No.	Type of Glass	Fiber Dia. Mils	Glass Wgt. Gms.	Preform Wrapped In	No. of Ends	Screen Type, Inner	Type of Metal
32	Bare Fiber Pref. No. 77	2	[illegible]	None	1	None	SC51A
33	Coromat	--	228	"	--	Al, 18x14	
34	Flexible Filter Mat	1.25	[illegible]	"	[illegible]	None	"
35	Bare Fiber Pref. No. 33 Flexible Filter Mat	1 1.25	[illegible] [illegible]	"	2	"	"
36	Flexible Filter Mat K75 Floccing	1.1 .5	400 30	18ga. Steel Wire	--	"	"
37	K75 Floccing	.5	1575	None	--	Al, 18x14	"
38	Bare Fiber Pref. No. 78	1	574	"	3	Al, 18x14	"
39	Bare Fiber Pref. No. 80	1	700	"	4	"	"
40	Flexible Filter Mat Coromat	1.25 --	400 50	"	--	"	"
41	Coromat	--	450	"	--	"	"
42	Bare Fiber Pref. No. 85	1	1044	"	4-5	"	"
43	Flexible Filter Mat	1.1	670	"	--	None	"
44	Flexible Filter Mat	1.1	640	"	--	"	"
45	Bare Fiber Pref. No. 83	1	742	"	3-4	Al, 18x14	Alcoa 32S with 7.36% Zn
46	Bare Fiber Pref. No. 87	1	559	"	4-5	Al, 2x2	SC51A
47	Bare Fiber Pref. No. 88 soaked in Styrene	1	713	"	3-4	Al, 8x8	"
48	Bare Fiber Pref. No. 81&82	1	622 601	"	3 4	Al, 18x14	"
50	Bare Fiber Pref. No. 91	2	1664	"	2	None	"
51	Bare Fiber Pref. No. 92 Soaked in Styrene/Xylene	2	1472	"	2	"	"
52	Bare Fiber Pref. No. 89 Coromat	2 --	1483 24	"	2	"	"
53	Bare Fiber Pref. No. 93	2	1800	"	2	6x6 Steel	"
54	Bare Fiber Pref. No. 90	2	1475	"	2	None	"
55	Bare Fiber Pref. No. 94	2	1439	"	2	Exp. Al	"
56	Coromat	--	285	"	--	Al, 18x14	"
57	Bare Fiber Pref. No. 62	2	250	Asbes., Corrug. Al, 18x14 Al Scr.	1	"	Alcoa 2S
58	Bare Fiber Pref. No. 63 Coromat	2 --	180 12	Stove Pipe	1	"	"
59	Bare Fib. Pref. No. 75 soaked in Polymethylmethacrylate	1	1080	None	2	None	SC51A
60	Bare Fiber Pref. No. 95	2	2067	"	2	"	"
61	Bare Fiber Pref. No. 96	2	1761	"	2	"	"
62	Bare Fiber Pref. No. 97	2	1818	Asbestos	2	Exp. Al	"
63	Bare Fiber Pref. No. 20 Coromat	1 --	243 20	Stove Pipe & Asbestos	3	Al, 18x14	"
64	Bare Fiber Pref. No. 98	2	1932	None	2	Exp. Al	"

Preform Wrapped In	No. of Ends	Screen Type, Inner	Type of Metal	Metal Wgt. Gms.	Flask Heater Type	Trough Type	Feed* Type	Temp. °F at Pour: Flask O.D.	Glass	Metal	RPM	Cast. Wgt. Gms.
ne	1	None	3551A	3200	Gas O.D.	End Pour	M	300	300	1500	3200	3500
"	--	Al, 18x14	"	3650	"	"	M	300	300	1500+	2332	3475
"	1-	None	"	2000	"	Bot. Pour	M	300	300	1500+	250	2000
"	2	"	"	2000	"	"	M	300	300	1500+	3231	2300
ga. Steel Wire	--	"	"	4150	None	End Pour	A	Room	Room	1500+	3302	4200
ne	--	Al, 18x11	"	3450	Radiant Gas ID	"	A	600	600	1500+	3414	4600
"	3	Al, 18x14	"	3200	None	"	MC	Room	Room	1500+	3290	3500
"	4	"	"	3650	Radiant Gas ID	"	MC	200	200	1500+	3306	4250
"	--	"	"	4540	"	"	MCR	200	200	1420	3309	4740
"	--	"	"	5100	None	"	MC	Room	Room	1500+	3285	5000
"	4-5	"	"	4994	Radiant Gas ID	"	A	400	400	1400	3227	6150
"	--	None	"	6810	"	"	M	400	400	1275	3193	6000
"	--	"	"	6810	"	"	A	400	400	1350	3090	6240
"	3-4	Al, 18x14	Alcoa 323 with 7.36% Zn	7310	"	"	A	350	350	1375	3170	7400
"	4-5	Al, 2x2	3551A	6810	None	"	ARF	Room	Room	1600+	3240	6975
"	3-4	Al, 8x8	"	6810	"	"	ARF	Room	Room	1500+	3220	7150
"	3 4	Al, 18x14	"	6810	Gas O.D.	"	ARF	700	--	1500	3227	6660
"	2	None	"	6800	None	"	ARF	Room	Room	1500+	3200	8100
"	2	"	"	6800	"	"	ARF	Room	Room	1500+	3200	7210
"	2	"	"	6800	"	"	ARF	Room	Room	1500+	3200	8055
"	2	6x6 Steel	"	6800	Gas O.D.	"	ARF	400	400	1500	3200	8675
"	2	None	"	5450	None	"	MC	Room	Room	1500	3200	6475
"	2	Exp. Al	"	5900	Gas O.D.	"	ARF	400	400	1500	3200	6610
"	--	Al, 18x14	"	5900	None	"	ARF	Room	Room	1500	3200	5245
sbes., Corrug. Al, 8x14 Al Scr.	1	"	Alcoa 2S	4540	Gas Flame ID	"	MCRF	600	600	1500	3200	5020
tove Pipe	1	"	"	4540	"	"	MRF	400	400	1500	3200	3580
one	2	None	3551A	3600	Gas O.D.	"	MRF	150	--	1200+	2825	4350
"	2	"	"	9050	Gas O.D. & Flame I.D.	"	MRFC	650	650	1200+	2772	9175
"	2	"	"	7750	Gas O.D.	"	MRF	450	350	1200+	3061	8710
sbestos	2	Exp. Al	"	8000	Gas Flame ID	"	MRF	400	400	1200+	3200	8720
tove Pipe & sbestos	3	Al, 18x14	"	1729	"	"	MRF	300	450	1300+	3200	--
one	2	Exp. Al	"	9078	"	"	MRF	450	460	1200+	3291	9960

Cast. No.	Type of Glass	Fiber Dia. Mils	Glass Wgt. Gms.	Preform Wrapped in	No. of Ends	Screen Type, Inner	Type of Metal	M Wg
65	Bare Fiber Pref. No. 99	2	472	Asbestos, Exp. Al Screen	2	Exp. Al	SC51A	
66	Bare Fiber Pref. No. 53	3	294	Stove Pipe, Exp. Al Screen	1	"	"	
67	Bare Fiber Pref. No. 102 Sulfur coated	2	689	Exp. Al Scr.	2	"	S5A	
68	Bare Fiber Pref. No. 107 soaked in Sodium Silicate	2	721	None	2	"	"	
69	Glass Cloth 16x14 Weave EG 401 Filter Media	--	645	"	--	None	SC51A	
70	Glass Cloth 16x14 Weave EG 401 Filter Media	--	710	"	--	"	"	
71	Plastic Coat, Fiberglas Screen 14x18, 525 wgt.	--	240	"	--	"	"	
72	1/2 Al.Coat.Fib.Pref.No.118	2	1628	"	2	Exp. Al	"	
73	1/2 Al.Coat.Fib.Pref.No.119	2	1300	"	2	None	"	
74	1/2 Al.Coat.Fib.Pref.No.116	2	367	Asbestos	2	Exp. Al	"	
75	1/2 Al.Coat.Fib.Pref.No.115	2	305	"	2	"	"	
76	Bare Fiber Pref. No. 106	2	1770	None	2	None	"	
77	Bare Fiber Pref. No. 105	2	1128	"	2	"	SC51A with 1%Cd, 1.5%Zn	

Castings No. R-1 through No. 31 were made in a 8-1/8" I.D. x 12-1/2" (inside length) Flask. Balance of castings were made in a 7-3/4" I.D. x 34" (inside length) Flask.

Castings No. R-1 through R-4 were made with resin bonded sand flask liners.
Castings No. 1 through 31 and No. 58 were made with sodium-silicate invert-sugar, CO_2 bonded sand flask liners. Balance of castings were made with no flask liners; but with colloidal graphite parting agent.

Castings No. R-1 through No. 23 were made with a hand crank trough traverse. Balance of castings were made with a motorized chain driven trough traverse, rate of 3 feet per minute.

* Feed Type: M = Poured manually
A = Poured automatically - tilting crucible, cam-operated synchronize
RFC = Flask rear to flask front to flask center (direction of feed)

Preform ...apped in	No. of Ends	Screen Type, Inner	Type of Metal	Metal Wgt.Gms.	Flask Heater Type	Trough Type	Feed* Type	Temp, °F at Pour Flask O.D.	Glass	Metal	RPM	Cast. Wgt. Gms.
...stos,Exp. ...creen	2	Exp. Al	SC51A	4[illegible]40	Gas Flame ID	End Pour	AFR	300	900	1200+	3200	3711
...e Pipe,Exp. ...creen	1	"	"	5448	"	"	AFRF	350	900	1200+	3200	1460
... Al Scr.	2	"	S5A	8400	None	"	MRF	Room	Room	1200	1400	8290
	2	"	"	7700	"	"	MFC	Room	Room	1400	3000	3208
	--	None	SC51A	6810	"	"	MFR	Room	Room	1300	1465	7030
	--	"	"	6810	"	"	MFR	Room	Room	1300	3344	4500
	--	"	"	7264	"	"	MFR	Room	Room	1400	2966	6705
	2	Exp. Al	"	5902	"	"	MFR	Room	Room	1300	3350	6873
	2	None	"	6810	"	"	MFR	Room	Room	1350	3265	7700
...stos	2	Exp. Al	"	6310	"	"	MFR	Room	Room	1300	3344	Gls.Sec. 3070
	2	"	"	7664	"	"	MFR	Room	Room	1400	3100	Gls.Sec. 4266
	2	None	"	8172	"	"	MFC	Room	Room	1500	3362	9480
	2	"	SC51A with 1%Cd,1.5%Zn	8173	"	"	MC	Room	Room	1500	3200	3860

... 8-1/8" I.D. x 12-1/2" (inside length)
.../4" I.D. x 34" (inside length) Flask.

...esin bonded sand flask liners.
... with sodium-silicate invert-sugar,
...stings were made with no flask liners;

... a hand crank trough traverse.
... chain driven trough traverse, rate

...ting crucible, cam-operated synchronized feed track.
... to flask center (direction of feed)

TABLE II

Cast. No.	Product Evaluation
R-1	Metal flowed through preform into asbestos wrap. Traveled through seam, between layers. Poor wetting of glass fibers.
R-2	Metal flowed around preform ends instead of through preform walls. Poor penetration. Poor wetting of fibers. See cut, Fig. VII, Second Annual Report.
R-3	Same as R-2. Aluminum froze in pores of screen.
R-4	Uneven wall thickness. No glass used.
1	Preform collapsed due possibly to excessive flask heat, and was scrapped prior to casting. Cast without glass.
2	Metal failed to penetrate glass strands. Froze in pores of screen support.
3	Same as #2. Very rough outer surface due to charred sugar and sand. Spotty penetration, poor wetting.
4	Same as #3. Very little percentage glass. Mostly concentrated at the inner surface. (Sectionalized for examination).
5	Heavy casting, partial penetration, poor fiber wetting.
6	Smooth but irregular outer surface due to buckling of tin plate. Otherwise same as #4. Cross section shows convolutions, uneven distribution of Fiberglas. (Sectionalized for examination).
7	Metal failed to penetrate glass, longitudinal cracks and screen exposure on inner wall.
8	Wrinkles, cracks and glass exposure similar to #6 (longitudinal section cut for tensile strength test, failed at low stress because of fiber concentration diagonally across gage length.)
9	Glass and screen exposure. Very poor penetration or wetting.
10	Exposed glass outer wall. Inner wall metal coated. Small degree of penetration, cold shuts apparent.
11	Exposed glass outer wall. Partial penetration. Longitudinal seam of stove pipe reproduced.

Table II

Cast. No.	Product Evaluation
12	Outer surface glass exposed. No penetration, no wetting.
13	Some surface glass in one area. Good penetration, uneven wall thickness, buckling of seam due to warping of stove pipe. (Sectionalized for examination).
14	Some surface glass. Good penetration. Similar to #13. (Sectionalized for examination).
15	Insufficient metal to cover all glass on inner and outer surfaces. Some cracks in inner wall. Penetration good, small percentage glass, smooth matte surface.
16	Smooth outside surface, some glass exposed, rough metal coat inner wall. Good penetration, poor in spots because of uneven pouring.
17	Thin layer of glass exposed with rough metal coat on inside wall. Convolutions of glass strands. Uneven wall thickness. (Sectionalized 6 sections for examination).
18	Good surfaces, some depressions in outer wall. Good penetration, small percentage glass. (Sectionalized transversely and longitudinally for examination).
19	Good inside wall, glass exposed on half outer wall area. Buckled seam to outer wall. Fair to good penetration.
20	Good inside wall, glass exposed on half of outer wall area. Even wall thickness (cast in iron pipe). Fair penetration, 1-2 strands, showing outside. See print, Figure III.
21	Similar to #20, but with smaller diameter aluminum coated fibers.
22	Even glass exposure on outside wall. Poor penetration (2S aluminum).
23	Even glass exposure on outside wall. Poor penetration, many cold shuts apparent, 2 strands exposed.
24	Some screen exposed on inside wall; even glass exposure on outside at ends, but good penetration otherwise.
25	Metal coated inside, exposed glass on outside at ends, fair penetration in middle, many cold shuts at surface.
26	Metal coated inside, some exposed glass on outside.
27	Uniform metal coated inside wall, glass exposed outside at ends. Fair penetration, uneven wall thickness.

Cast. No.	Product Evaluation
28	Good ringing tone, best to date. Scant metal on inside wall front end, some glass exposed outside, good penetration.
29	Metal coated inside, glass exposed outside.
30	Some screen exposed inside, glass exposed outside. Turned down on lathe, shows non-uniform penetration, non-uniform distribution of fiber strands.
31	Glass exposed front end, fair penetration. Insufficient metal, uneven wall thickness end to end-cold shuts.
32	Appearance excellent compared to previous castings. Fair penetration, many small cold shuts.
33	Smooth outside, glass exposed inside. Variation in wall thickness, metal penetrated to outside in areas but glass unwetted, highly compressed and concentrated at inner wall.
34	Poor, metal flowed around preform ends, glass not wetted, poor penetration.
35	Poor, metal flowed between preform and flexible filter mat wrap, outside unevenly coated.
36	Smooth appearance, insufficient metal, glass unwetted, penetration poor, glass highly compressed to fraction of original volume.
37	After turning down in lathe, areas of dry glass were exposed indicating poor penetration.
38	Good sound casting, some glass exposed outside, easily scraped off.
39	Good sound casting, glass exposed outside, poor penetration.
40	Smooth inside, glass exposed over half casting surface, poor penetration. Other end smooth.
41	Same as #40, poor wetting, uneven glass distribution.
42	Some inside screen exposed, outside glass exposed, fair penetration. See print, Figure III, showing cylinder after ends squared, uncoated glass brushed off.
43	Poor penetration and wetting, glass compressed, concentrated inner surface. Glass exposed in areas on outside.

Table II

Table II

Cast. No.	Product Evaluation
44	Glass compressed, concentrated at inner surface, smooth outside Coromat layer - See print, Figure III.
45	Some inside screen exposed, outside glass exposed, about 7 strands thick, full length of cylinder, poor penetration. See print, Figure III; also shows some end flow.
46	Fair appearance inside, glass exposed outside, similar to #45, poorer penetration.
47	Fair appearance inside, glass exposed outside, penetration fair, fibers not wetted, however.
48	Fair appearance inside, glass exposed outside, fair penetration, fibers not wetted.
50	Good metal coat inside, glass exposed outside, easily scraped off. Uneven wall thickness. Glass bunched up near middle, not penetrated.
51	Good metal coat inside, glass exposed outside, easily scraped off. Similar to #50, penetration not as good. See print, Figure IV, showing end flow due to contraction of preform, bunched fibers not penetrated.
52	Good metal coat inside, Coromat glass exposed outside, easily scraped and burned off. Similar to #50.
53	Some inside screen exposed (heavy steel mesh), glass bridged, glass exposed outside, easily scraped off. Similar to #50 in penetration.
54	Poor metal coat inside, glass exposed, bridged, otherwise similar to #50.
55	Poor inner wall, screen exposed, glass exposed, bridged, poor wetting, penetration.
56	Poor penetration, wetting large areas bare glass.
57	Screen melted inside, glass exposed, layers of aluminum coated asbestos outside, poor wetting, penetration.
58	Rough granular surface, charred, fair penetration.
59	Glass exposed inside, some bare glass outside, cold shuts evident; poor uneven penetration.
60	Glass exposed inside. See photomicrograph (Figure VII) showing penetration and fiber distribution at spot 3" from front end (poured rear to front) after light cut inside and out. Lower right corner is inside wall. Some bare glass exposed on outside, easily scraped off.

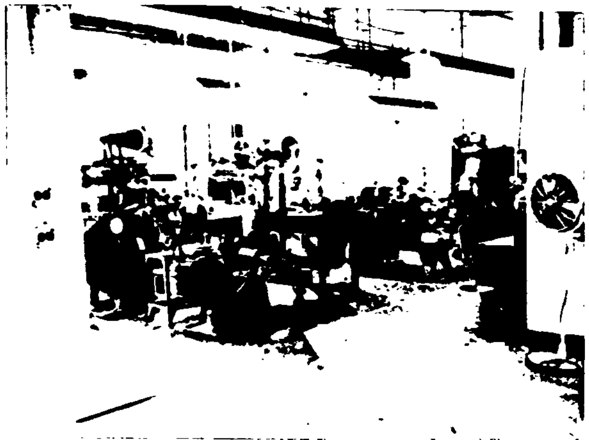
Table II

Cast. No.	Product Evaluation
61	Some glass exposed inside, bunched glass areas evident, some bare and metal coated glass exposed outside, easily scraped off. See photo of turned cross section showing uneven distribution of glass strands (Figure VI).
62	Some glass and screen exposed inside, bunched glass areas exposed, fair penetration, uneven wall thickness.
63	Poor, insufficient metal, smooth surface due to metal flow around preform ends.
64	Some bridged glass inside, fair penetration to outside surface except for small area of poor penetration, bunched glass in narrow band.
65	Poor wetting, glass concentrated on inner surface, metal seams and cracks on outside wall.
66	Very smooth outside, glass concentrated and exposed inside, uneven wall thickness, longitudinal seam full casting length.
67	Some inner screen exposed, some glass exposed outside, very poor penetration.
68	Some metal coated screen and glass exposed inside, strands consolidated, cold shuts evident, fibers not penetrated.
69	Cloth bridged, several layers bare on inside wall. Glass cloth surface, seam evident, poor ends. See print, Figure IV.
70	Similar to #69.
71	Dirty casting but regular shape, screen-pattern appearance, fairly uniform wall, good penetration. See print, Figure IV. Staple fibers not penetrated, but weave is.
72	Some screen exposed inside, poor surfaces, glass exposed 2/3 outside wall.
73	Excellent surfaces, little surface glass evident, heavy wall, section shows uneven glass distribution.
74	Some screen faintly visible, asbestos coated surface, lapped edges.
75	Overflow technique, long tube, poor penetration, surfaces not good.

Cast. No.	Product Evaluation
76	Metal coated inside. Small amount of glass bridged. Outside appearance, some bare glass exposed at mid-section. Metal flow around ends.
77	Poor penetration.

	Average Centrifugal Casting Length	Wall Thickness	Casting Weight
R-1 through #31	12 1/2"	1/4 to 1/2"	1800 to 4700 gm.
#32 through #74	13 to 23"	1/4 to 5/8"	1460 to 9960 gm.

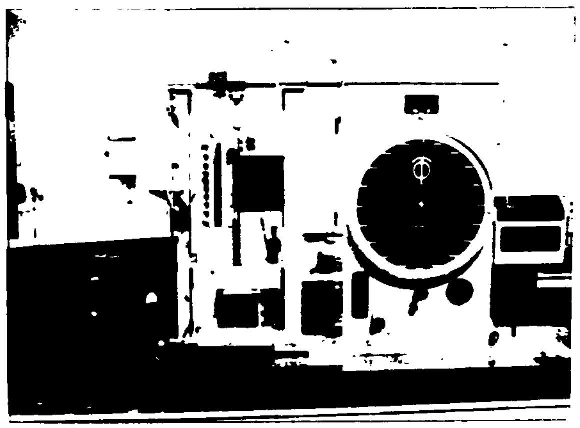
OLIN METALS-GLASS
LABORATORY FACILITIES
NEW HAVEN, CONN., SEPT., 1957



MACHINE SHOP AREA

HYDRAULIC AND BLISS PRESSES

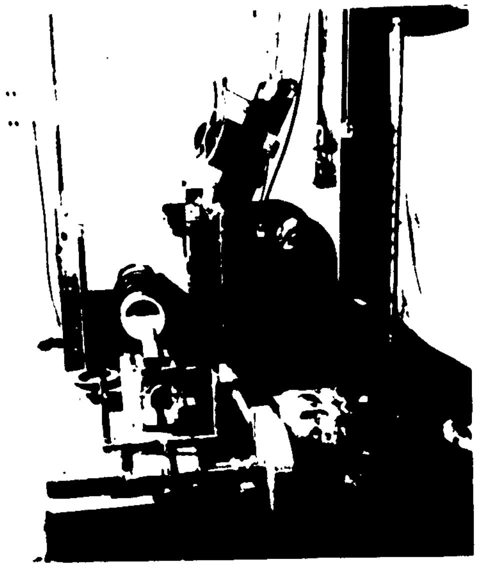
PHYSICAL CHEM. LAB. AREA



PHYSICAL TESTING LAB. FACILITIES

FIGURE [illegible]

[illegible]



[illegible]

77 [illegible]

[illegible]

FOUR GRA CAST CYLINDERS

FIGURE III

FOUR GRA CAST CYLINDERS

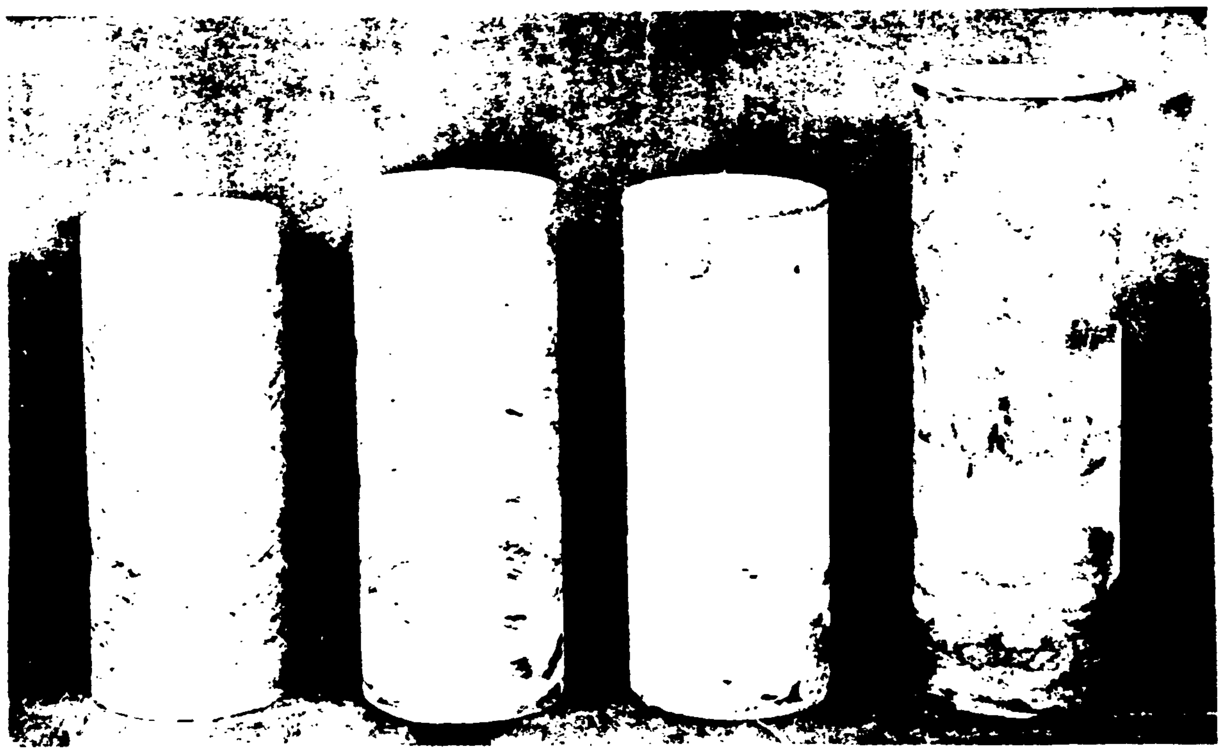
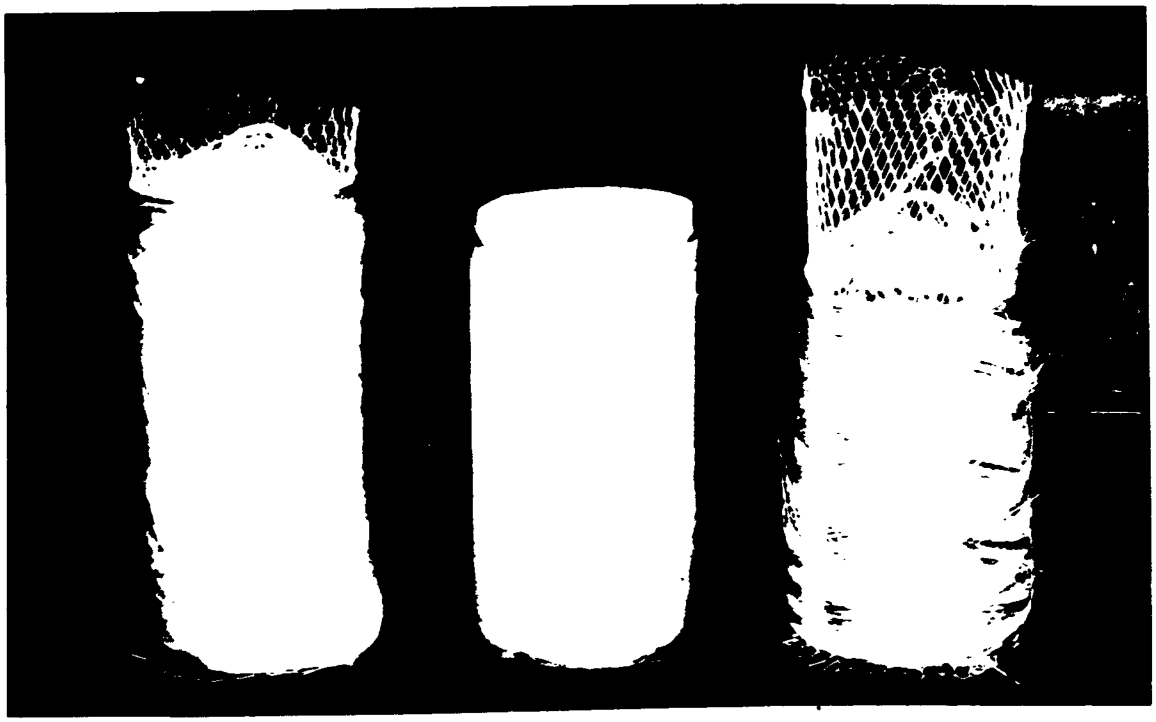


FIGURE IV

VARIOUS TYPES OF HELICALLY WOUND FIBERGLAS
PREFORMS AND SCREEN SUPPORTS

6" NOMINAL ID



BAREFIBER 2 mil 502 grams 2 end	BAREFIBER 1 mil 267 grams 1 end	HALFCOATED (Al) FIBER 2 mil 424 grams 2 end

FIGURE V

CROSS SECTION GRA CASTING

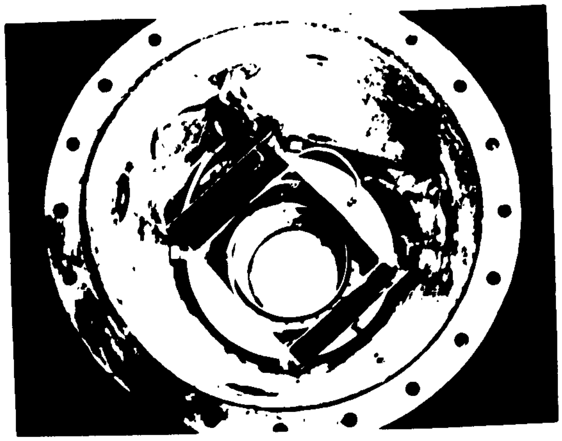
CASTING No. 61 SHOWING UNEVEN DISTRIBUTION OF FIBERGLAS STRANDS

FIGURE VI

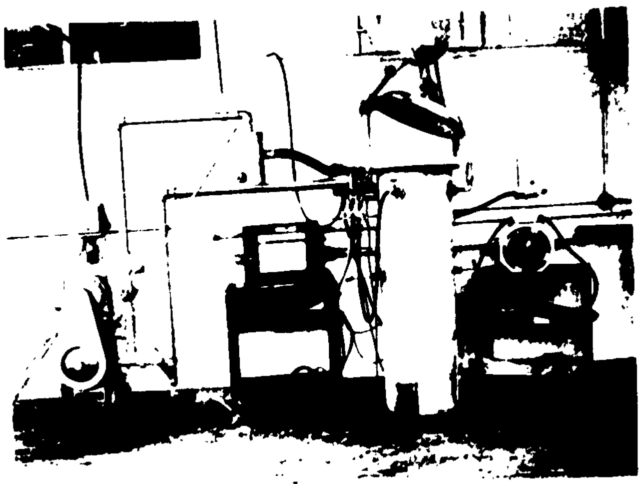
PHOTOMICROGRAPH
LONGITUDINAL SECTION CASTING No. 60
[redacted] 60 X

FIGURE VII

VACUUM IMPREGNATION UNIT



TOP VIEW



FRONT VIEW

FIGURE VIII

VI APPENDIX B

SINGLE FIBER TENSILE STRENGTH VS APPLICATION TEMPERATURE OF VARIOUS COATING ALLOYS

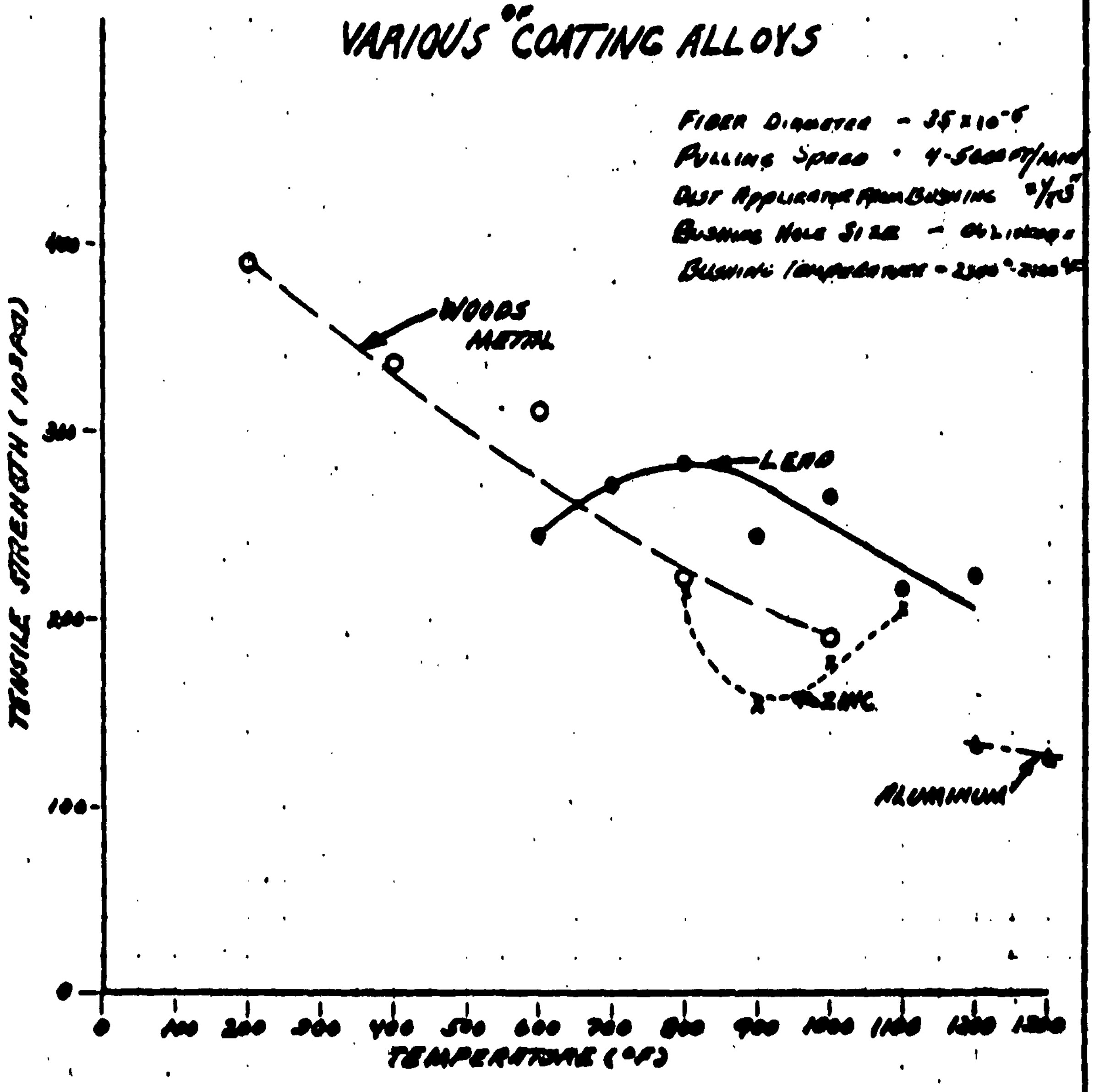


FIGURE 9

END OF REEL

JOB NO. B-45561

THIS MICROFILM IS THE PROPERTY OF THE UNITED STATES GOVERNMENT

MICROFILMED BY
DEFENSE PRINTING SERVICE—WASHINGTON
MICROFILM SECTION