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SEVENTH QUARTERLY REPORT

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MANUFACTURING METHODS AND TECHNOLOGY PROJECT TO ESTABLISH PRODUCTION TECHNIQUES TO MANUFACTURE RIGID ARMOR FOR RADAR ANTENNA HARDENING

LEVEL III

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REPORT PERIOD

1 DECEMBER 1978 TO 28 FEBRUARY 1979

TECHNICAL SUPPORT DIRECTORATE
UNITED STATES ARMY ELECTRONICS
RESEARCH AND DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY

PREPARED UNDER CONTRACT NO. DAAB07-77-C-0476

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PREPAPED BY

SWEDLOW, INC.
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ABSTRACT

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Technical fabrication problems were reassessed and subscale process development initiated to solve these problems.

Subscale panels, fabricated during the period, demonstrated progress in the elimination of several of the processing problems. Overall panel opacity, surface delaminations, and voids or trapped air were brought under control.

The reduction of preconditioning temperatures to less than 180°F and a reduction of the lamination time eliminated the opacity problem.

Application of a woven polypropylene fabric as protective face plies eliminated the surface delamination or non-lamination problem on the limited number of samples fabricated this period.

The utilization of silicone sponge rubber seals improved the degassing efficiency and evacuation capabilities during processing. Minimal voids or air entrapment were the result.

The process revisions required to accomplish the above were defined.

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CONTENTS

1.0 PURPOSE

The purpose of this program is to establish production techniques and production capabilities for the manufacture of armor panels. The armor panels are intended for use with flat radar antennae to provide protection from munitions fragments.

The armor panels will be flat molded sheets of various sizes and edge finishes. The sheets will be molded from cross-plied assemblies of unidirectionally oriented, blown film made from a dielectric grade polypropylene. A protective over-lay will be molded into the panel surfaces and camouflage will be incorporated in or onto a portion of the panels.

The program is divided into four tasks as described below:

Step 1 Engineering Samples

Two sets of two each panels will be produced in order to demonstrate the ballistic capabilities of the selected materials and processes.

Step 2 Confirmatory Samples

Ten sets of two each panels of various sizes, thicknesses, and camouflaging methods will be produced in order to demonstrate the total capabilities of the panels in regards to environmental stability, electronic transmission, and ballistic characteristics. In addition, camouflaging techniques and panel trim and edge fusing will be demonstrated.

Step 3 Pilot Run

Thirty-two sets of two each panels will be produced in order to demonstrate the capacity of each production step and verify the capability of the line to fabricate at an acceptable rate.

Step 4 Production Capability Demonstration

An in-plant demonstration will be held in order to show the production capabilities of the pilot production line to invited representatives of industry and government.

The first quarterly report described in detail the program objectives, tasks, and schedule.

2.0 INTRODUCTION

The following report covers the period from December 1, 1978 to February 28, 1979.

During this period the technical problems encountered during the program were reassessed and subscale process development initiated to solve them.

The subscale panels fabricated during this period demonstrated progress in the elimination of overall opacity, surface defects, and elimination of voids or trapped air. Remaining development problems include elimination of striations (stress whitening) thickness and warpage control and a scale-up of the processes.

In the following section the various defects encountered during the program are discussed. Methods employed to correct these defects are presented.

Process steps used to produce panels during this period are described as is the latest seal configuration developed for the revised process.

3.0 PROCESS DEVELOPMENT

3.1 General

During the last period, full scale panels were fabricated in both 3/8-inches and 1-inch thickness. The panels exhibited major surface and minor subsurface defects. A revised procedure employed in subscale process development during this same period improved control of several of these defect areas.

Panel Defects

- Surface whiteness and panel opacity
- Surface and subsurface delaminations
- Voids and/or trapped air pockets
- Whitish striations (stress whitening)
- Nominal thickness and thickness tolerance variations
- Warpage

During the last period surface whiteness and opacity was eliminated by reducing the temperature of all preconditioning steps to less than 180°F. Surface and subsurface delamination defects were decreased by the above change and a solvent prewash of the protective film. However, surface delaminations remained an intermittently recurring problem when using balanced film protective cover plies such as Hercules B-500.

Voids and/or trapped air pockets and the whitish striations remained unsolved problems last period. Thickness and warpage control techniques were also not fully determined.

3.2 Defect Causes - Corrective Action

In order to attempt to solve processing problems, a theory of the probable defect causes is defined and corrective action taken or proposed is discussed below.

Surface Whitening and Panel Opacity

Although in some isolated cases panel opacitity may be caused by contamination, the major causes appear to be orientation release of the oriented film during pre-conditioning or over heat of the panel during the lamination cycle. The orientation release temperature being pressure related occurs at a relatively low temperature during the preconditioning when the film is subjected to vacuum pressure only.

Panel opacity occurs during lamination at temperatures over 350°F and is temperature-time related. Rapid discoloration occurs at temperatures over 355°F and much more slowly below 355°F.

Corrective Action

Reduction of all preconditioning temperatures to below 180°F and the decrease of lamination time at the upper temperatures has eliminated the opacity problem in all 3/8-inch thick panels fabricated during this period.

Surface and Subsurface Delaminations

Contaminants such as film lubricants, oil from film handling, and air or moisture trapped between plies are examples of introduced contamination that cause both surface and subsurface delamination. In addition, integral material modifiers such as plasticizers, stabilizers, non blockers, found in protective films can also cause delamination or non-lamination.

Thermal gradients that occur during panel cool down are also believed to induce shear stresses that may jeopardize the panel laminations. Severe in-plane stresses develop at the panel surfaces due to contraction of the outer surfaces during cool down and the restriction of this contraction by the still hot interior.

Corrective Action

Decreasing the number of protective film plies, solvent cleaning these plies, and cutting them undersize to the panel decreased surface delaminations when using thin balanced oriented film as protective surface materials. However, these results did not entirely eliminate the surface problems suggesting that integral contamination and/or the inability of the film to cope with in-plane surface motions was, on occasion, causing surface delamination.

During this period a woven polypropylene fabric, Propex Style I-89 was incorporated as a protective surfacing material. This material manufactured by AMOCO Fabrics Company of Atlanta, Georgia shows promise as a solution to the surface lamination problem. In addition, the woven material provides superior surface integrity due to its interwoven nature and incorporates an ultra-violet stabilizer that should improve panel weathering characteristics.

Voids and/or Trapped Air Pockets

Panels fabricated during the last period showed marked improvements as noted in the above sections. The voids or trapped air problem, however, was not significantly improved, although some panels fabricated this period were essentially void free.

The multi-ply nature of the prelaminated film stack presents a very large intra-ply area of trapped air that must be eliminated. Film overlaps and film winding spaces provide natural pockets and seal off areas that tend to prevent void elimination by pressure alone. Any surface moisture pick-up by the film must also be eliminated in order to prevent outgassing during the high temperature lamination process.

Corrective Action

Two major processing step changes were employed in the void free panels fabricated during this period as compared with process used in fabrication of the less successful panels last period. One change involved the allowable leakage employed during the two periods. Although a minimum 29-inch Hg vacuum was used during both periods, the leakage allowable (as measured by the vacuum drop with the evacuated assembly closed off) was reduced. Last period a vacuum drop of two-inches Hg within a five minute period was allowed. During this period, the maximum drop within a ten minute period was limited to one-inch Hg. This represents an allowable volume leakage reduction to one-quarter of the previous control.

The second change involved the initial evacuation step and the preconditioning of the film stack. Employment of silicone sponge rubber seals (described in Section 5.0 and illustrated in Figures 8 and 9) allows for initial film stack compression simultaneously with evacuation. Additionally, the compressive resistance of the seal limits the stack compression and leaves a somewhat loose stack during the important moisture and air removal (preconditioning) cycle.

In a separate exploratory panel molding, thin rubber pads were placed between the flat rigid caul plates at both panel faces and the panel was laminated without the aid of evacuation. Resulting panels had only minimal air entrapment. This would indicate that a more uniform application of pressure as accomplished by use of the rubber pads is effective in elimination of voids and offers a possible alternate, lower cost processing method that may be suitable for some applications.

Whitish Striations (Stress Whitening)

Striations of whitish discolorations occur to a greater or lesser extent in most panel laminated using rigid metal caul plates. The striations, located in the central region, follow the film winding pattern and intersect at right angles. The most severe discolorations occur at the striation intersections. There seems to be a repeating pattern that occurs on about 2 1/2-inch centers as shown below in Figure 1. This pattern may be characteristic of a single mandrel winding or setting.

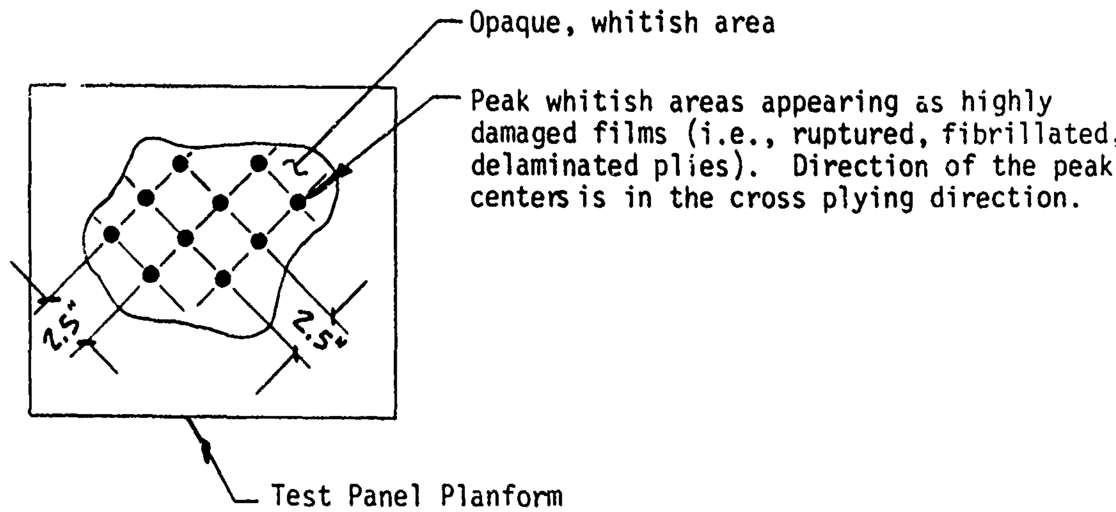


Figure 1. STRIATION PATTERN

It is surmised that the striations are caused by a buildup of ply overlaps that cause local high pressure zones that initiate the stress whitening. Figure 2 below illustrates overlap buildups that would cause a striation. It is obvious that at striation intersections the ply buildup is additive and therefore most severe.

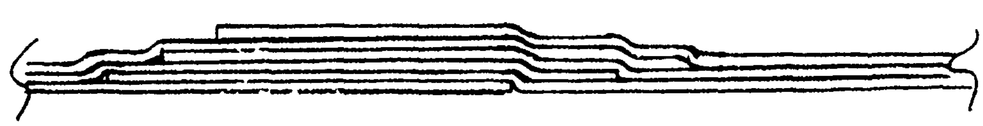


Figure 2. OVERLAP ILLUSTRATION

This condition could either be the result of a repeating pattern or random highs and lows resulting from a random winding pattern. The central panel location of the defect is consistent with edge related flow and restricted flow in the plane form central region.

As noted in the previous section, a limited experiment was conducted wherein a rubber face sheet was used in an attempt to relieve high local stress areas and more uniformly distribute applied pressures. Surface flatness control was, of course, poor but there was no appearance of the whitish striations.

Corrective Action

As noted above a rubber pressure distribution pad eliminates the striations. The resulting surface distortion on both sides varies from the flat plane up to 0.015-inches when using a 1/32-inch thick silicone rubber pad on both faces of a 3/8-inch thick panel. Examination of a limited number of tries showed that a single ply of woven polypropylene fabric Propex I-89 protective face ply appeared to decrease but not eliminate the problem.

Multiple plies of I-89 fabric on the panel faces or a combination of very thin pressure distribution pads with protective surface plies I-89 are possibilities that have not yet been tried.

Investigation of cross-ply winding techniques in pursuit of greater winding uniformity would be beneficial.

Nominal Thickness and Thickness Tolerance Variations

Control of panel thickness has been attempted by two different methods, loose stack thickness measurements and loose stack weights. Using either method, the resulting panel thickness is dependent on the pressure, temperature, and time variables of the lamination cycle. In addition, however, the degree of local overlap buildup (the mechanism that causes the striation discussed in the previous section) also affects final thickness. Increased local overlaps will tend to produce increased thickness.

Thickness tolerance ranges to date have been random with the two following exceptions. When molding between flat metal caul plates the laminated panels are consistently thicker in the mid panel region. Panels molded using a rubber pressure pad have random thicknesses across the panel and a smaller tolerance zone. These results are again consistent with restricted flow in the panel central region.

Corrective Action

Thickness control is expected to improve as procedures are fixed. In addition, any method of control or minimization of the effect of the local buildup problem should make thickness control easier.

Other methods of measuring loose film stacks to provide thickness control information should be tried. One possibility would be loose film thickness measurements between flat plates at some given pressure.

Warpage

Panel warpage has been attributed to two processing effects. Panel edge restrictions or edge pressure during laminating and differential temperatures between the panel faces during cool down result in warpage.

Corrective Action

Present processing procedures, as described in the following section, avoid any panel edge pressure during the lamination cycle. This eliminates warpage from this cause but also precludes net panel edge molding.

Control of face temperature during cool down is a function of the laminating equipment platens, equipment controls, and tooling. Some difficulty has been encountered in control of these temperatures due to differences in press platen mass and variations in cooling passage flow rates. Selective adjustment in cooling fluid flow rates are being investigated as a control method in this area.

Lightly clamping panels against flat plates during the 200°F heat treat removes a portion of the panel warpage.

4.0 PANEL FABRICATION

During this period several panels were fabricated using silicone sponge rubber seals. The fabrication procedures employed were essentially the same as that developed during the end of the last period with the incorporation of revisions discussed in the previous section.

In addition to creating the vacuum chamber between caul plates with sponge rubber seals, the allowable vacuum chanber leakage was reduced, and the woven polypropylene fabric protective face plies were incorporated. Panels were fabricated using caul plates only and both silicone rubber and teflon pressure pads.

A schematic of the processing steps is shown in Figure 3.

4.1 Woven Polypropylene Fabric

A woven polypropylene fabric was successfully employed as a protective surface material in several subscale panel laminations. In all cases, the panel surfaces were without delamination or other defects.

When molded against flat metal caul plates, the woven fabric produced a smooth even surface with the fabric weave barely discernible. When molded using a flexible surface pad, the fabric pattern was accentuated and noticeably visible but still fused together in a continuous face ply.

The material used was Propex Style 1-89 woven polypropylene fabric. This material is manufactured by AMOCO Fabric Company, Patchogue Plymouth Division, Atlanta, Georgia. Some of the properties are noted below:

Tensile Strength	ASTM-1682	275 x 230 lbs/inch
UV Resistance, Strength Retention	FTMS No. 191 Method 5304 1000 Hours	>70 percent
Weight		6.0 oz/sq yd

The material is presently available in pigmented configuration only and contains an ultra-violet stabilizer.

The pigmentation increases surface opacity and masks off the smaller subsurface defects. Examination of the subsurface using a strong background light showed that the striation pattern was still in evidence on non pad augmented moldings.

REMOVE CROSS-PLIED PADS FROM CONTAINER

↓

STRIP OFF PROTECTIVE FILM AND THREE TO FIVE ADDITIONAL PLIES. DISCARD ANY MATERIAL WITH EXCESSIVE WRINKLES

↓

COMBINE PADS TO A PREDETERMINED WEIGHT AND RECORD LOOSE THICKNESS

↓

POWER PAPER SHEAR ASSEMBLY TO MOLDING SIZE

↓

ADD WOVEN POLYPROPYLENE PROTECTIVE FABRIC TO EACH FACE

↓

POSITION SEAL FRAMES, OPEN CELL URETHANE FOAM, AND INSERT MONITORING THERMOCOUPLES

↓

EVACUATE TO OVER 29-INCHES Hg (CHECK CLOSED OFF ASSEMBLY - MUST HOLD 29-INCHES Hg MINIMUM AFTER 10 MINUTES)

↓

CONDITION EVACUATED STACK AT 170 - 180°F IN A CIRCULATING AIR OVEN FOR 15 HRS MINIMUM

↓

COMPRESSION MOLD ASSEMBLY AS FOLLOWS:

1) LOAD IN 180°F MAXIMUM PREHEATED PRESS (MAINTAIN VACUUM)

2) APPLY 2200 PSI PRESSURE

3) RAISE CAUL PLATE TEMPERATURE RAPIDLY to 340°F AND THEN MORE SLOWLY TO 355°F

4) MAINTAIN 355°F PLATEN TEMPERATURE UNTIL THE MID STACK TEMPERATURE REACHES 350°F

5) AT THE MID STACK TEMPERATURE OF 350°F, COOL DOWN TO 300°F

6) AT 300°F DECREASE THE COOL DOWN RATE AND CONCENTRATE ON MINIMIZING FACE TO FACE TEMPERATURE DIFFERENCES

↓

REMOVE, INSPECT, AND TRIM

Figure 3. FLOW DIAGRAM

Figure 5 "Woven Polypropylene Face Ply Lamination" describes the molding assembly and the molding cycle used to fabricate these panels.

4.2 Pressure Pads

Two of the subscale panels fabricated during this period employed 1/32" silicone rubber pressure pads. One panel was laminated entirely without vacuum while the other employed the latest vacuum seal design and high vacuum throughout the cycle.

The resulting panels were both translucent and without striations or any whitish opaque areas. The evacuated panel was almost without voids or trapped air pockets while the non-evacuated panel contained only small and mostly edge associated voids.

Figure 6 "Rubber Pad Lamination" illustrates this method of lamination using both rubber pad and panel evacuation.

A 1/16-inch thick teflon (TFE) pressure pad was used on the faces of another of the subscale panel moldings. The resulting surface irregularities were much less pronounced than those obtained when using 1/32-inch thick rubber pads. However, the teflon "cold flowed" under the high molding pressures causing panel edge distortion problems. This problem coupled with the high cost of the material would seem to eliminate teflon as a practical pressure pad material.

Figure 7 "Teflon Pad Lamination" illustrates the use of teflon pads while laminating.

4.3 Molding Procedure

The panel laminations were all preceded by a vacuum seal evaluation followed by an oven preconditioning cycle.

Prior to molding, the evacuated assembly was checked by closing off the chamber for 10 minutes and noting vacuum gauge drop. A drop to no less than 29-inches Hg indicates a satisfactorily sealed assembly. The vacuum was maintained throughout the lamination process.

Panels were then preconditioned to remove air and moisture at 160-180°F while under vacuum.

The panel was then ready for the press lamination cycle. Constant pressure and full vacuum were maintained throughout this cycle.

The lamination procedure chosen was intended to accomplish the following:

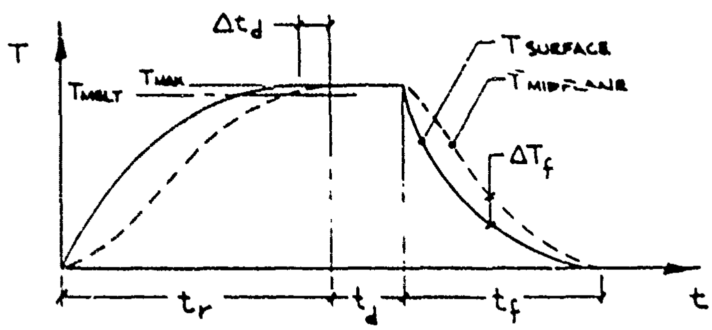
- Maintain preconditioning temperature well below orientation release temperature

- Maintain high vacuum throughout process (where applicable)

- Effect rapid heat-up during molding - slowing only near maximum temperature to prevent temperature over shoot

- Effect rapid cool down while attempting to minimize temperature differences between panel face to face and face to mid-panel.

The temperature and pressure control are defined in Figure 4 below:



Symbols:

T = Temperature

t = time

Subscripts:

r = rise

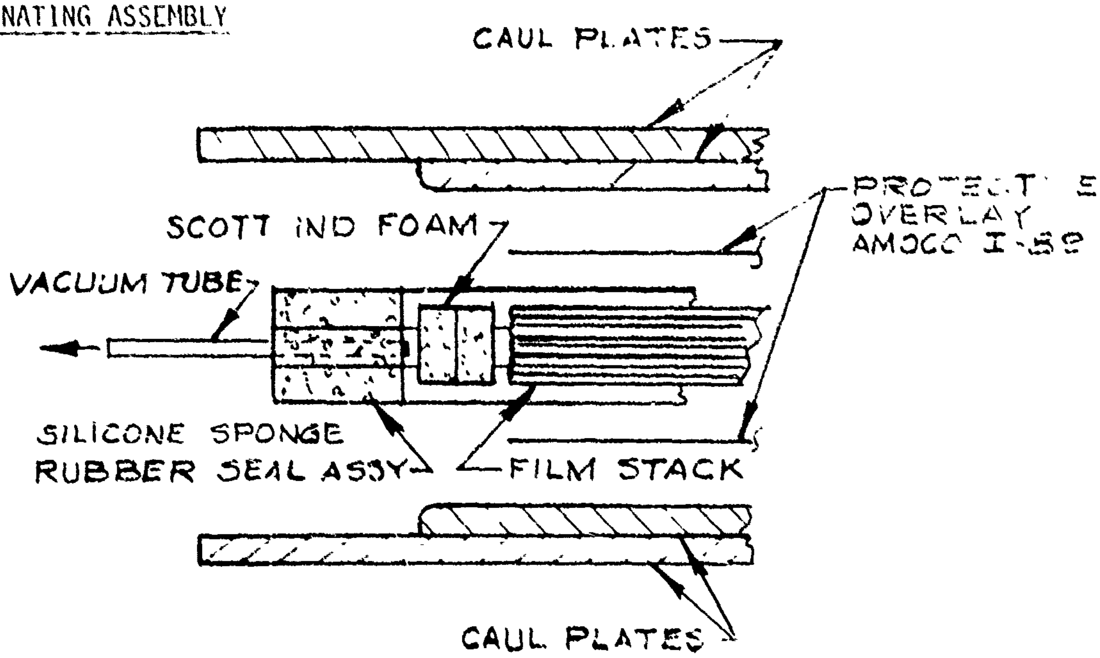
d = dwell

f - fall

Figure 4

Illustrations (Figures 5, 6 and 7) describe the laminating assembly and procedures used to fabricate the various panels fabricated during this period.

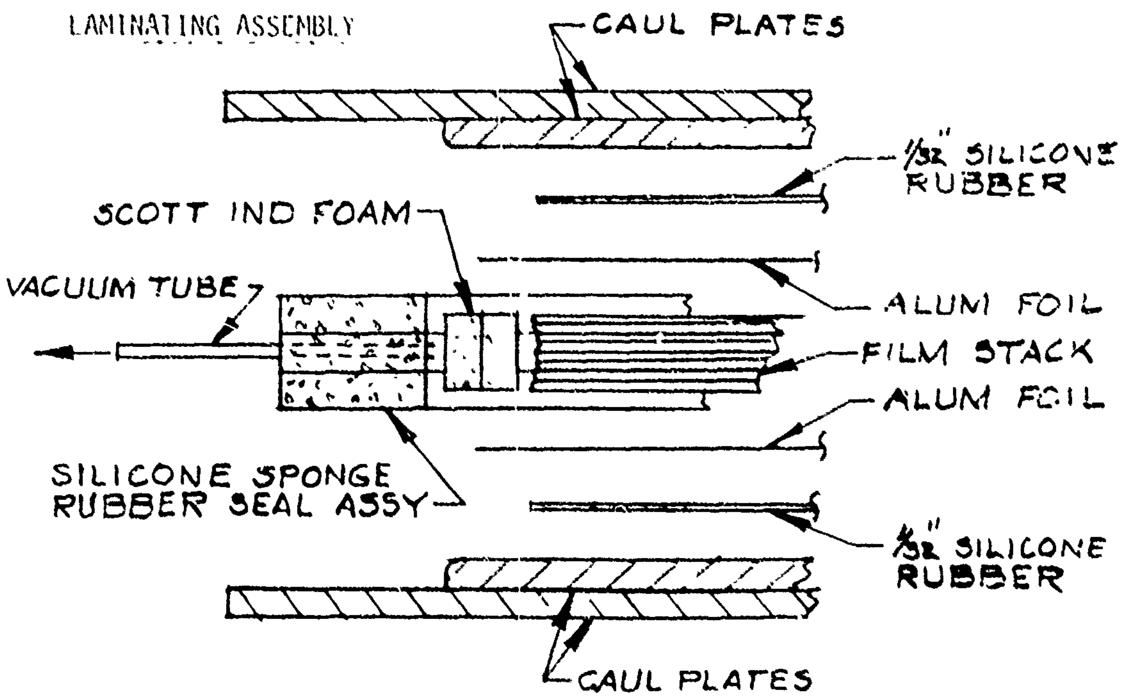
LAMINATING ASSEMBLY



LAMINATION CYCLE

Initial vacuum check		Vacuum drop to 29.7-inches Hg in 10 minutes
Preconditioning		15 hours at 170°F at 29-30-inches Hg
Heatup time (Room temperature to 350°F)	t_r	60 minutes (mid panel)
Dwell time (Time at or above 350°F)	t_d	5 minutes (mid panel)
Cool down time (350°F to room temperature)	t_f	70 minutes (mid panel)
Maximum temperature	T_{max}	352°F (mid panel)
Maximum temperature differential		
Face to Face	ΔT_1	19°F
Face to mid panel	ΔT_2	23°F
Pressure	P	2200 psi
Vacuum		30-inches Hg

Figure 5. WOVEN POLYPROPYLENE FACE PLY LAMINATION

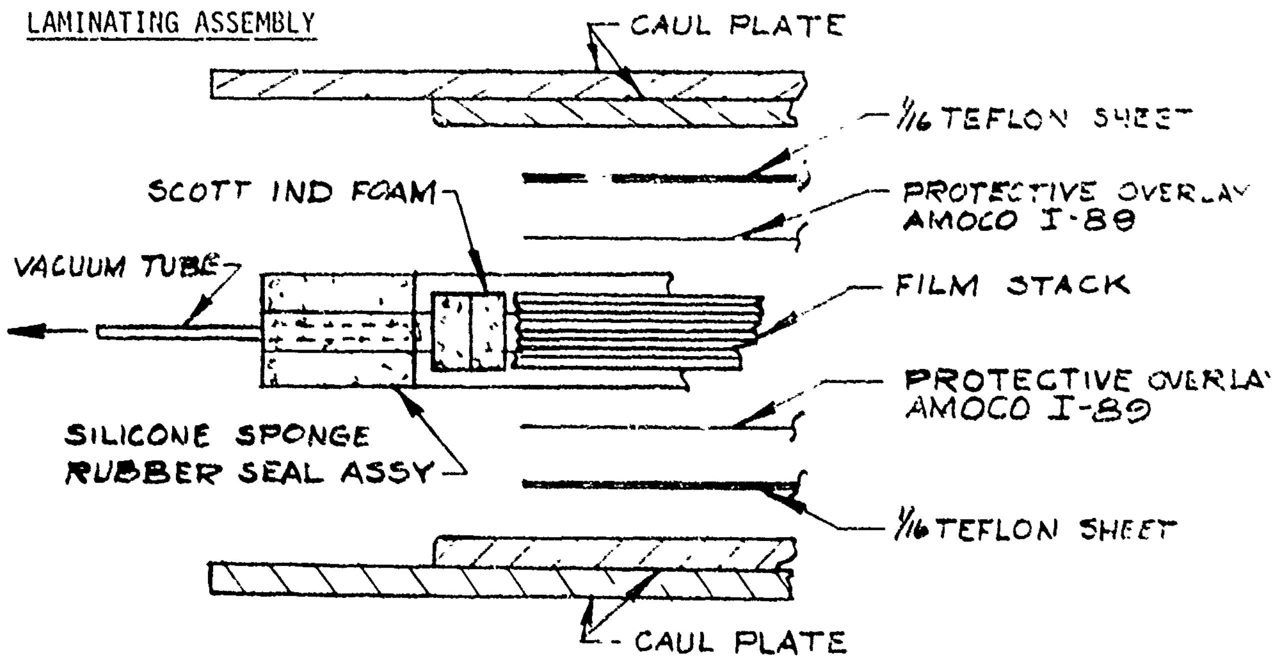


LAMINATION CYCLE

Initial vacuum check		Vacuum drop to 25.5-inches in 10 minutes
Preconditioning		15 hours at 170°F and 29-20-inches Hg
Heatup time (Room temperature to 350°F	t_r	60 minutes (mid panel)
Dwell time (Time at or above 350°F)	t_d	5 minutes (mid panel)
Cool down time (350°F to room temperature)	t_f	75 minutes (mid panel)
Maximum temperature	T_{max}	352°F
Maximum temperature differential		
Face to Face	ΔT_1	9°F
Face to mid panel	ΔT_2	18°F
Pressure	P	2200 psi
Vacuum		30-inches Hg

Figure 6. RUBBER PAD LAMINATION

LAMINATING ASSEMBLY



LAMINATION CYCLE

Initial vacuum check		Vacuum drop to 29.0-inches Hg in 10 minutes
Preconditioning		15 hours at 170°F and 29-30-inches Hg
Heatup time (Room temperature to 350°F)	t_r	67 minutes (mid panel)
Dwell time (Time at or above 350°F)	t_d	3 minutes (mid panel)
Cool down time (350°F to room temperature)	t_f	70 minutes (mid panel)
Maximum temperature	T_{max}	351°F (mid panel)
Maximum temperature differential		
Face to Face	ΔT_1	10°F
Face to mid panel	ΔT_2	19°F
Pressure	P	2200 psi
Vacuum		30-inches Hg

Figure 7. TEFLON PAD LAMINATION

5.0 SILICONE SPONGE RUBBER SEALS

During this period sponge rubber seal materials were evaluated. The best performer was selected and fabricated into subscale seals. The seals were evaluated during panel fabrication and then redesigned to a more optimum configuration.

5.1 Seal Materials

Four silicone sponge rubber seal materials were evaluated. Two of the materials are specification manufactured to AMS 3195 TE12 and AMS 3195 TE 18. The other materials were Connecticut Hard Rubber products COHR-10470 and COHR-10480.

Testing at various degrees of compression and at molding cycle temperatures showed that seal compression must be held under 50 percent if the seal is to have multi cycle possibilities. The COHR-10480 material demonstrated superior performance due to its lower compressive set characteristics.

5.2 Seal Design

The silicone sponge rubber seal is required to make a vacuum seal between the caul plates at the loose stack heighth and then to compress to final molding thickness.

In order to do this and limit the seal compression to less than 50 percent, seals are used in conjunction with internal caul plates. Figures 8 and 9 "Seal Compression" show the loose stack as initially captured and the seal in its final compressed state.

Figures 10 and 11 show the proposed full scale seal design. The three-inch high seal (Figure 9) requires two 1/8-inch thick aluminum frames in order to prevent collapse during evacuation.

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CHECKED BY:	SEAL COMPRESSION 3/8" PANEL	REPORT NO.
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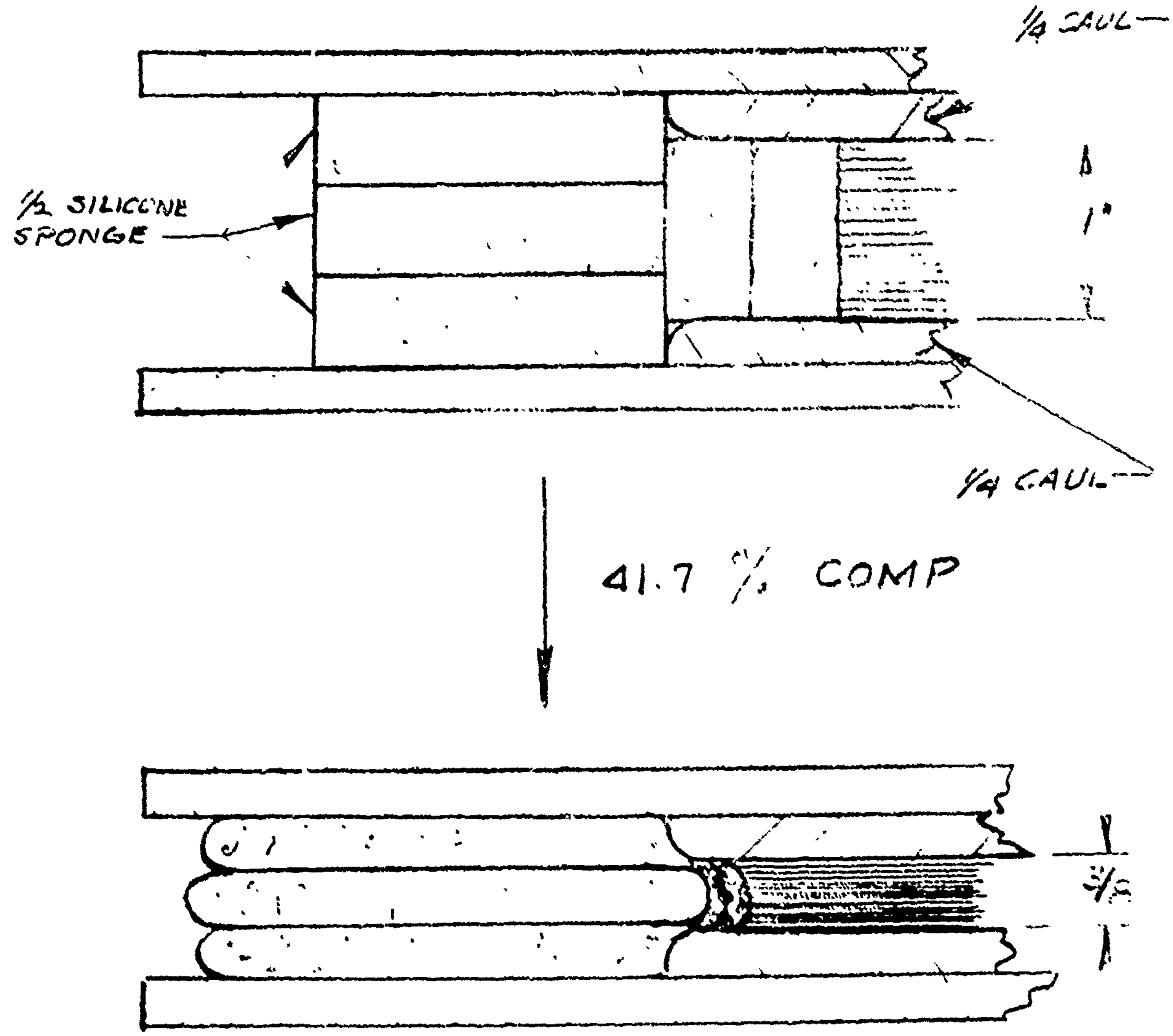

Figure 8. SEAL COMPRESSION - 3/8-Inch PANEL

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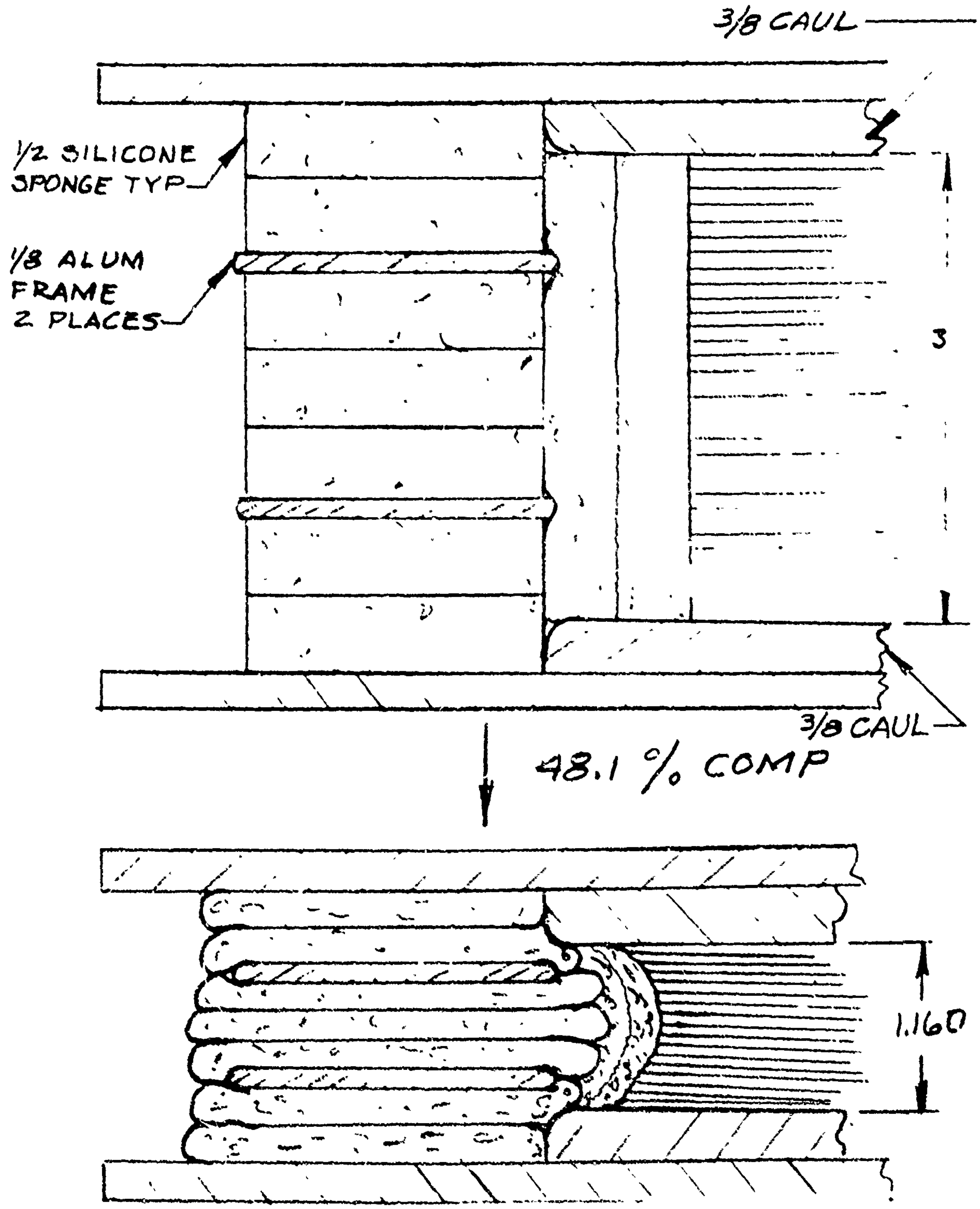

Figure 9. SEAL COMPRESSION - 1-Inch PANEL

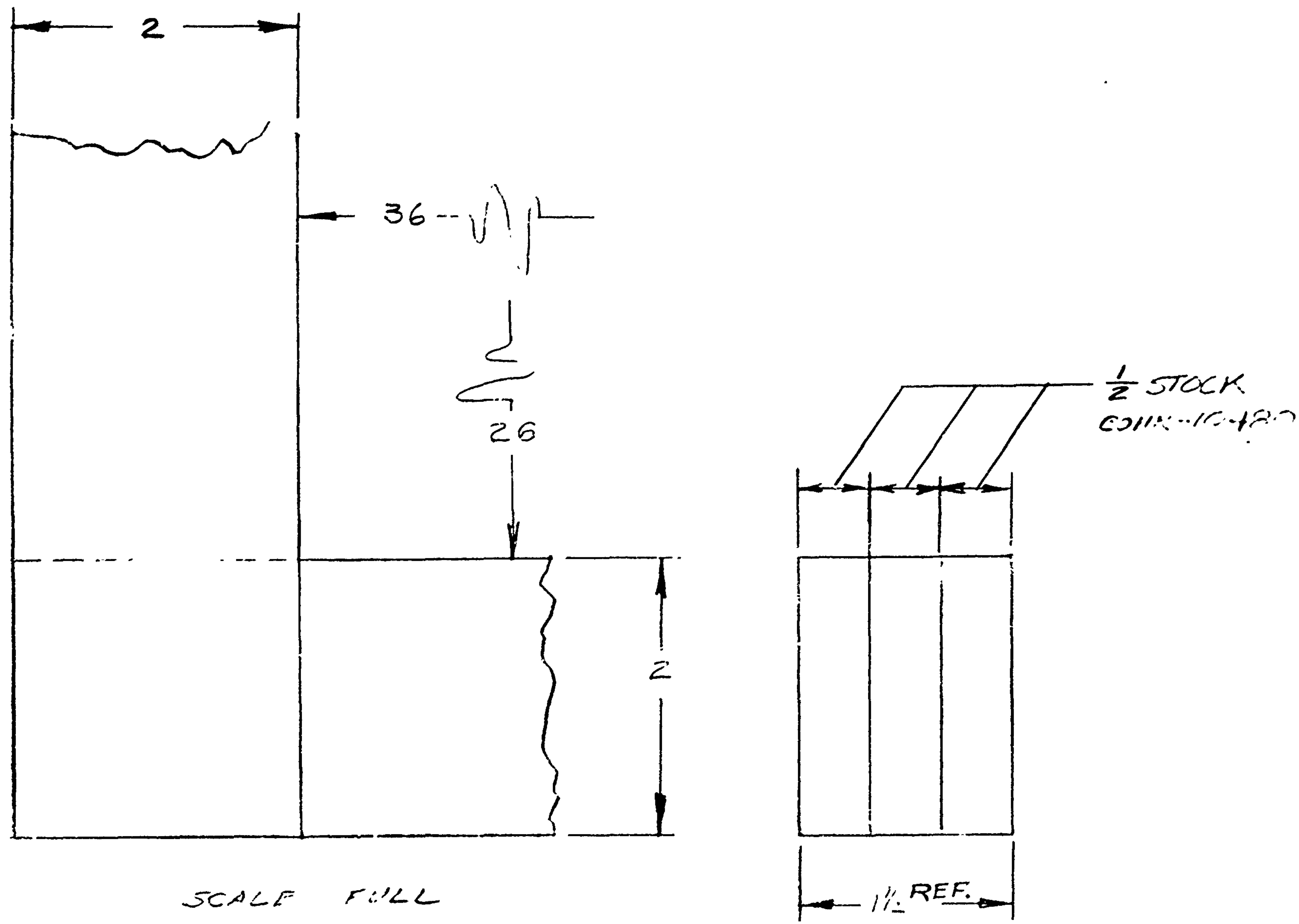

Figure 10. SEAL - 3/8" x 24" x 34" PANEL

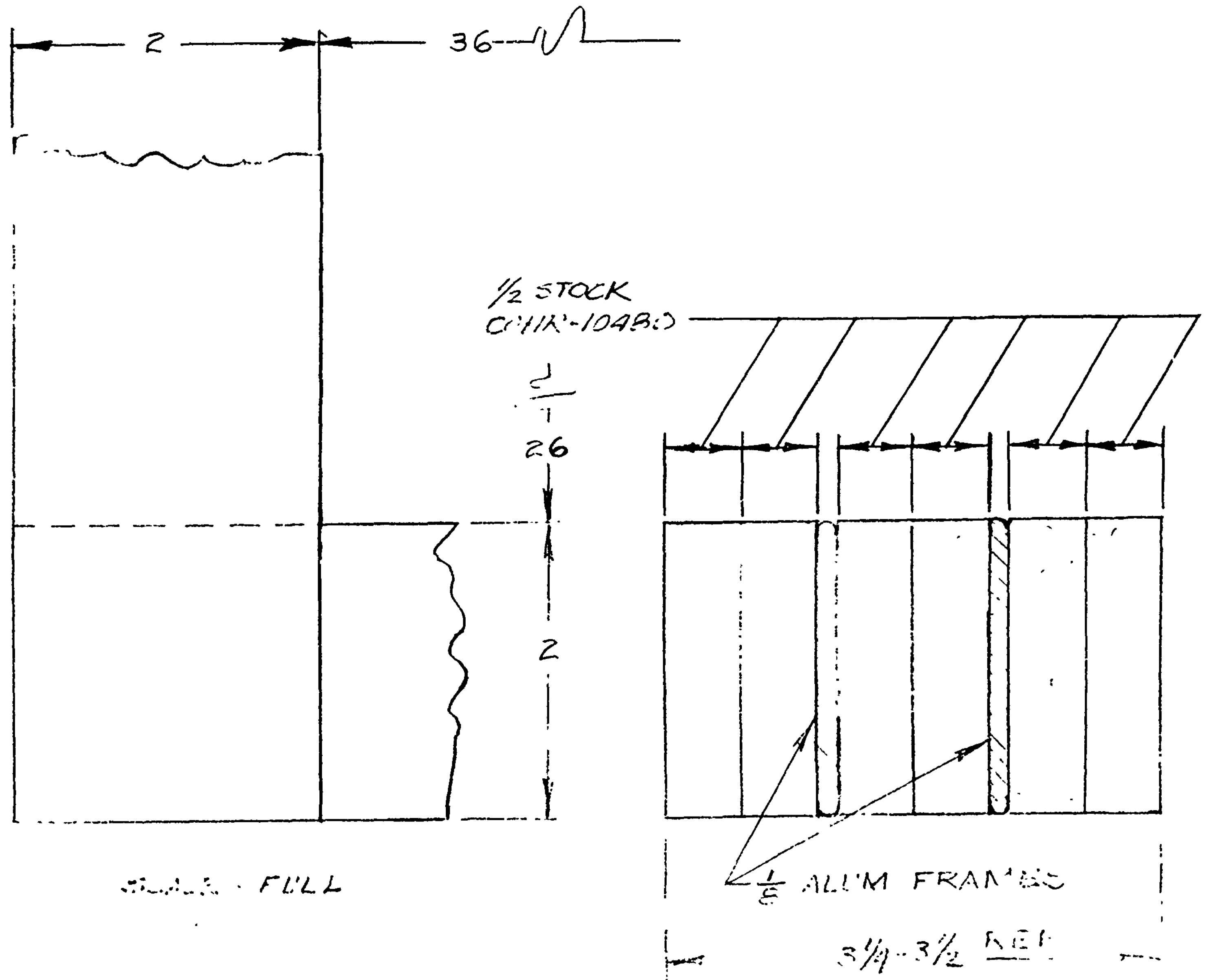

Figure 11. SEAL - 1" x 24" x 34" PANEL

6.0 PROBLEM AREAS

6.1 Program Schedule Revisions

As the objectives of this program have not been achieved within the originally scheduled time period, a major program rescheduling is required.

6.2 Remaining Technical Problems

Although surface condition problems, trapped air/voids, and overall panel opacity problems appear to be under control using the latest processing procedures, the striations (stress whitening) thickness control and warpage control require further investigation.

7.0 PROGRAM FOR NEXT PERIOD

7.1 Schedule Revision

Prepare and present a revised scheme for overcoming the technical problems and reschedule the program in accordance with this plan.

7.2 Full Scale Seals

Fabricate full scale silicone sponge rubber seal assemblies.

7.3 Subscale Process Development

Repeat successful processing procedures developed during this period in conjunction with the investigation of remaining technical problems.

7.4 Full Scale Process Development

Upon accomplishment of repeatable successful subscale panel fabrication, start investigation of scale-up problem.