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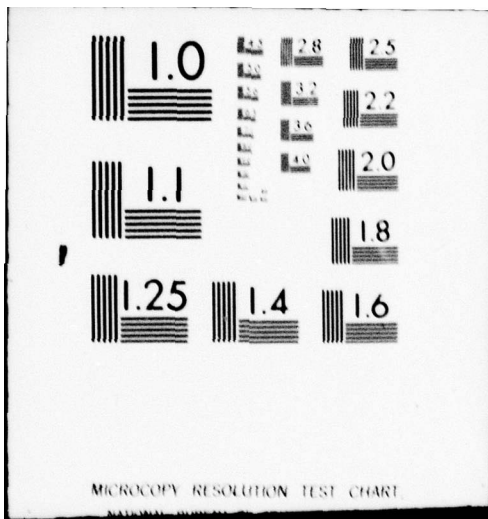
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LOW COST PLASTIC ACTUATOR
PROCESS DEVELOPMENT

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FOREWORD

This document is the final report on a study entitled, "Low Cost Plastic Actuator Process Development." The work was performed under project 1987, task 01 from April, 1976, to December, 1976, by Martin Marietta Corporation, Orlando, Florida, under Air Force Contract No. F33615-76-C-3086 AFFDL.

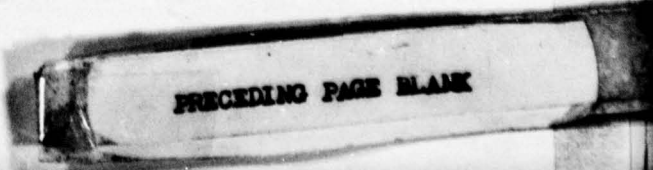
The work was administered under the direction of the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, 45433, by Mr. Thomas D. Lewis, AFFDL/FGL, Project Manager.

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SECTION I

INTRODUCTION

Under previously conducted Contract F33615-74-C-3013, a low cost plastic control surface hydraulic actuator was successfully developed to meet the performance and stringent environmental requirements for a Maverick type missile application. Three complete actuators were fabricated and tested. A cost analysis showed that a savings of over 33% could be realized through the use of molded plastic rather than machined metal parts when fabricated in quantities of 2000. A search was made for a material which could operate at +270°F and the 8 most likely candidates were subjected to preliminary testing to determine suitability. It was determined that a compression molded 65% glass filled polyimide was the only one suitable for this application. During the course of the program, it was recognized that the molded aft case containing the hydraulic cylinders was the critical item from a strength standpoint. A total of 24 aft cases were molded, using 4 molding processes, and tested to failure by the application of hydraulic pressure. The failures, consisting almost exclusively of pin hole leaks, occurred at widely varying pressures (1500 to 5000 psig). Approximately 35% passed the 2888 psig proof pressure requirement. Selected high strength parts were used to complete the program. Detail results are described in technical report AFFDL-TR-75-120.

The effort under this contract was directed at developing a means to provide a consistently high yield of high strength molded aft case parts. Experience gained on the previous effort was used to establish a molding process plan. A representative number of test samples were molded using full preforms systematically varying glass fiber length in the material, molding processes and procedures. The test samples were then tested to failure by hydraulic pressurization of both cylinders. Test results showed that 92% of the parts made using the best procedures and processes and made from the best material tried passed the 2888 psig proof pressure requirement. Detail results of this effort are included in this report.

SECTION II

PROBLEM DEFINITION AND PROGRAM PLAN

Under contract F33615-74-C-3013, a plastic actuator shown in Figure 1 was designed and fabricated. The aft case half which contains the critical pressurized cylinders is the part to which the pressure fittings attach as shown in Figure 1. However, out of 37 aft cases built, only 10 were acceptable, with 13 not completely molded parts and 14 not withstanding design pressure. Mold design, process descriptions, and test results from this previous contract are summarized for reference. In addition, possible solutions to the acceptability problem and a plan to evaluate alternative molding processes are presented in this section.

2.1 Mold Description

Figure 2 shows the finished mold. The complete mold consists of:

- 1) Cavity
- 2) Punch
- 3) Inserts
- 4) Ejection mechanism
- 5) Loading zone
- 6) Mold bases and closure guide pins
- 7) Cal-rod heaters and thermocouples.

2.1.1 Cavity

The cavity is the female negative of the aft portion of the actuator case (Figure 3). This cavity was formed by first machining two graphite electrodes that have an exterior shape identical to the aft case. These two electrodes (roughing and final) were used to machine the cavity by the electron discharge machining (EDM) process. The cavity block was made from degassed 4130 mold steel. Not shown in Figure 3 are four 3/8-inch diameter hold-in screws which were added at the top of the cavity. They help retain the molded aft case in the cavity upon punch withdrawal. Two of these screws are shown in Figure 4.

2.1.2 Punch

The punch is shown in Figure 5. It consists of a large steel block which has been machined to fit within 0.020 inch inside the loading zone

Figure 1. Plastic Actuator Case Developed
Under Contract F33615-74-C-3013

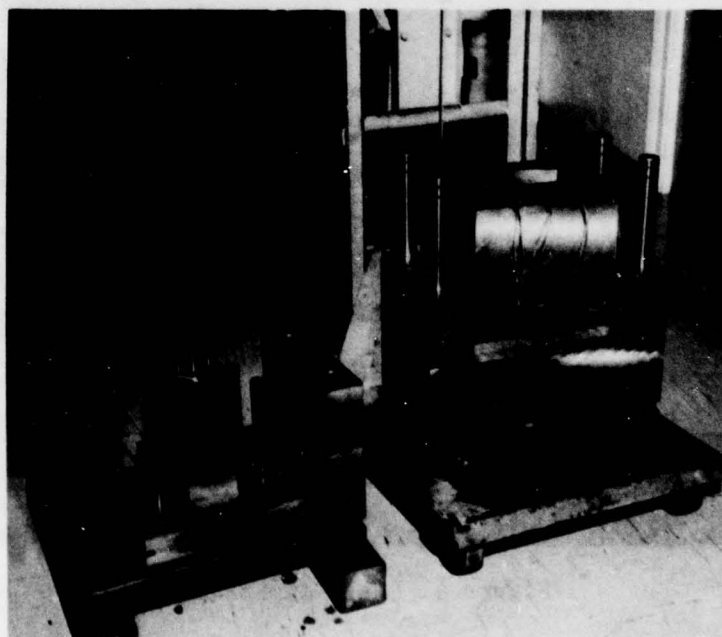


Figure 2. Mold Parts

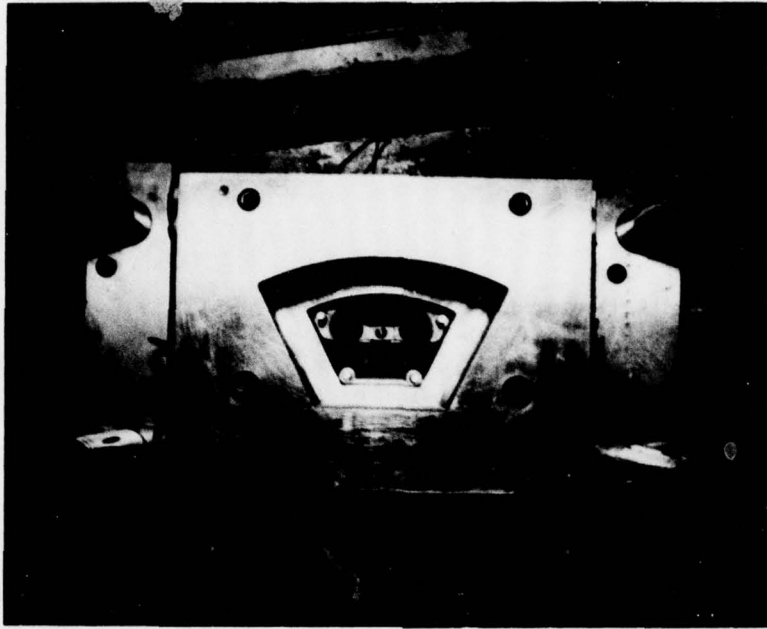


Figure 3. Cavity

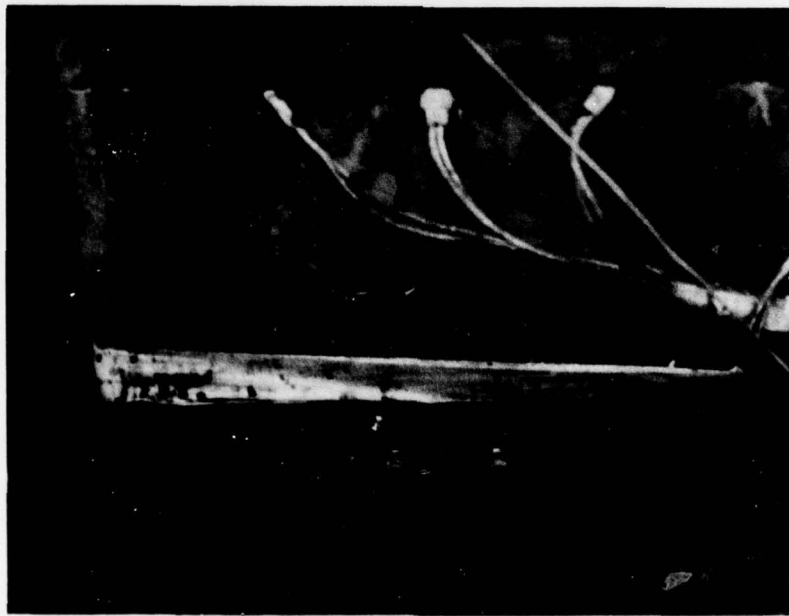


Figure 4. Hold-in Screws

cavity shown in Figure 3. A case hardened steel foot plate 1 inch thick is mounted to the base of the block and fits the loading zone cavity with 0.005 inch tolerances around its periphery. Removable steel pins are mounted to the base of the foot plate and form the cylinder cavities. A machined block which also mounts to the foot plate forms the inside of the aft case cavity and shaft bearing grooves. All dimensions are identical to the design prints. No draft was machined on the cylinder pins.

2.1.3 Inserts

As shown in Figure 6, inserts were made to form the O-ring seats and screw threads associated with the piston guides and pin lock housing. Three inserts were machined that slip over pins that protrude from the mold base. A fourth insert is inserted into the bottom of the cavity that forms the return port threads and O-ring seat. When inserted into the cavity, this insert is held by a pronged fork that inserts into the side of the cavity. Consequently, after the part is molded, the punch can be withdrawn first while the molded part remains fixed in the cavity. The pronged fork is then withdrawn and the four hold-in screws at the top of the cavity are also backed out releasing the molded part so that it can be ejected by the ejection mechanism.

2.1.4 Ejection Mechanism

Two 7/8-inch chrome-plated movable steel pins protrude through the bottom of the cavity directly under the cylinders. These ejection pins rest on a steel bar which passes under the cavity. As the bar is raised, the pins push the molded aft case part out of the cavity.

2.1.5 Loading Zone

The loading zone also appears in Figure 3. It is mounted on top of the cavity and accepts the bulk resin or preforms before closing the punch. The cross-sectional area of the loading zone cavity is twice the projected area of the cavity beneath it. This size accommodates the large amount of bulk resin which must be heated and compressed into the cavity below. The resulting molded part consequently has a thin "flash" which conforms to the loading zone area.

2.1.6 Mold Bases and Closure Guide Pins

The cavity is mounted on the lower mold base which raises the cavity approximately 5 inches off the lower press platen. This clearance allows a stout ejection bar to pass under the cavity. The punch mounts to the upper mold base. Both bases have grooves to which tiedown clamps are fastened for mounting to the press platens. The closure guide pins appear in Figure 2. These pins assure alignment of the punch/loading zone/cavity combination as the punch closes.

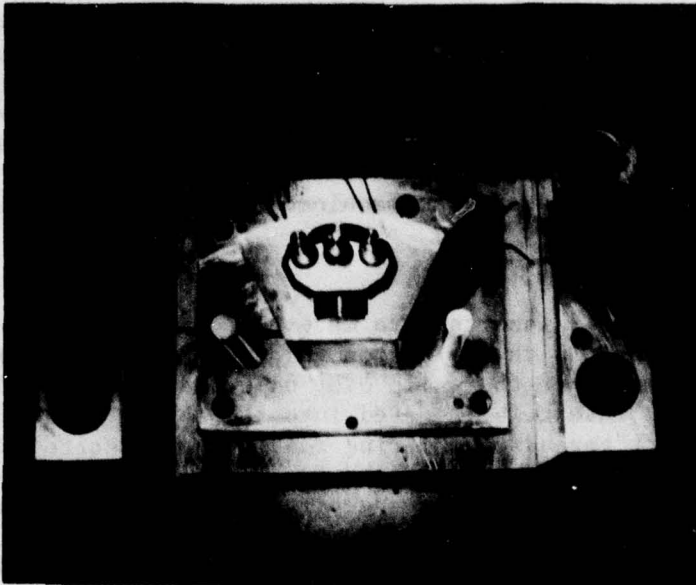


Figure 5. Punch

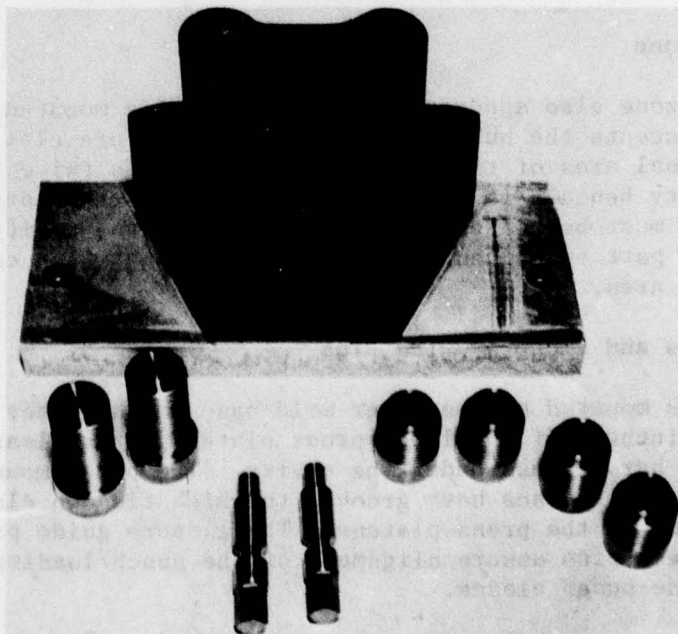


Figure 6. Mold Inserts and EDM Electrode

2.1.7 Cal-Rod Heaters and Thermocouples

To heat the cavity, punch, and loading zone, both upper and lower platens are heated up to 600°F by built-in platen heaters with adjustable controls at the press control console. In addition, 24 cal-rod heaters are contained within the mold. These heaters are controlled by five 110-volt Variacs. Iron-constantan thermocouples sense temperature at four locations:

- 1 On the case-hardened foot plate of the punch
- 2 At the front of the split line between cavity and loading zone
- 3 At the rear of the split line between cavity and loading zone
- 4 At the bottom of the cavity.

2.2 Previous Process Description (Contract F33615-74-C-3013)

Five basic processes for molding aft cases were tried under the previous contract, as described in AFFDL-TR-120 and Table I. In addition, several post-curing cycles and molding pressures were tried which are also identified in Table I. All resin used in this original molding process was Rhodia No. 5504, which is a polyimide resin that contains 65 percent by weight 1/4-inch glass fibers.

2.2.1 Raw Resin, Slow Process

The first successful parts were made by the raw resin, slow process. The resin is loaded into an 8 x 8 x 1-1/2-inch Teflon box with trap door bottom. The resin-filled box is inserted into a LaRose dielectric heater for 8 minutes while the resin temperature reaches 250°F. The box is then slid onto a carrying board and is transferred to a loading funnel. This funnel allows the preheated resin to fall through an opening into a 250°F mold. The press is then closed and the temperature is taken as rapidly as possible to 450°F (approximately 1 hour elapsed time). The part is then ejected and subjected to post-cure.

2.2.2 Raw Resin, Fast Process

The raw resin, fast process uses the same preheating cycle, but loads the resin into a mold which is already at 450°F. The part remains in the mold at 450°F for approximately 15 minutes for cure, then is ejected. Post-cure follows. The strongest part made was by this process.

2.2.3 Pelletized Preform, Moderate Temperature Process

Pelletized preforms, 1-1/2 inches in diameter by 1-3/4 inches high, are made by subjecting 30 grams of resin to 4500 psi pre-cure at 230°F for 75 seconds. These pellets are heated in a 250°F oven for 15 minutes

TABLE I

Process and Pressure Test Results
From Report AFFDL-TR-75-120

| Pressure Capability (psi) | | Molding Process (Section Number) | Comments (Exceptions, Post-cures, Press Force) |
|---------------------------|---------|----------------------------------|--|
| Bore A | Bore B | | |
| 2500 | 2700 | 2.2.1 | Ejection pins up when loaded. Post-cured 20 hr at 480°F. 66 tons. |
| 4640 | >5000 | 2.2.2 | Ejection pins up when loaded. Post-cured 20 hr at 212°F. 68 tons. |
| 3300 | 2500 | 2.2.2 | Ejection pins up when loaded. Post-cured 20 hr at 480°F. 68 tons. |
| 3150 | 2450 | 2.2.2 | Ejection pins up when loaded. Post-cured 20 hr at 480°F. 69 tons. |
| 3000 | 2680 | 2.2.2 | Ejection pins down when loaded. Post-cured 24 hr at 480°F. 75 tons. |
| 2980 | 3320 | 2.2.2 | Ejection pins down when loaded. Post-cured 24 hr at 480°F. 75 tons. |
| 2460 | 2600 | 2.2.2 | Ejection pins down when loaded. Post-cured 24 hr at 480°F. 75 tons. |
| 2400 | 2420 | 2.2.2 | Pins up. Resin in vacuum 2 hr. Post-cured 20 hr at 290°F. 68 tons. |
| 3320 | 3840 | 2.2.2 | Pins down. Resin in vacuum 2 hr. Post-cured 20 hr at 290°F. 68 tons. |
| 3340 | No Test | 2.2.3* | Part removed from mold at 400°F. Post-cured 16 hr at 390°F. 45 tons. |
| 2850 | 4440 | 2.2.3 | Part removed from mold at 400°F. Post-cured 20 hr at 290°F. 47 tons. |
| 2380 | 2740 | 2.2.3 | Part removed from mold at 400°F. Post-cured 20 hr at 290°F. 48 tons. |
| 2000 | 1660 | 2.2.3 | Part removed from mold at 400°F. Post-cured 16 hr at 475°F. 45 tons. |
| - | - | 2.2.5 | Fiberite short-fiber resin used. |
| 1600 | 3580 | 2.2.4 | Loaded at 400°F for 25 minutes. No post-cure. 68 tons. |
| 2600 | 2240 | 2.2.4 | Loaded at 400°F for 30 minutes. No post-cure. 65 tons. |
| 2860 | 3160 | 2.2.4 | Loaded at 400°F for 30 minutes. No post-cure. 65 tons. |
| 2740 | 3640 | 2.2.4 | Loaded at 400°F for 25 minutes. No post-cure. 65 tons. |
| 4020 | 4320 | 2.2.3 | Cooled in mold. No post-cure. 48 tons. |
| >2700 | 2150 | 2.2.3 | Cooled in mold. No post-cure. 48 tons. |
| >2700 | >2700 | 2.2.3 | Removed from mold at 330°F. No post-cure. 48 tons. |
| >2700 | >2700 | 2.2.3 | Cooled in mold. No post-cure. 48 tons. |
| >2700 | >2700 | 2.2.3 | Removed from mold at 330°F. No post-cure. 48 tons. |
| 2500 | >2700 | 2.2.3 | Cooled in mold. No post-cure. 48 tons. |
| 2845 | 3010 | Averages | |
| 2926 | | | |

*All subsequent loadings made with pins down.

and then placed in the dielectric preheater for 4-1/3 minutes. The pellets are then compressed in a 330°F mold and are held for 5 minutes at this temperature. The mold temperature is increased to 400°F as quickly as possible and held there for 10 minutes. At this point, one of two cures is instituted:

- 1) The punch is withdrawn approximately 1 inch and the heat is cut. When temperature reaches 330°F, the part is ejected, inserts are removed, and the part is placed in an oven for post-cure and cooling.
- 2) The cure is the same, except that the part is cooled in the mold, then ejected and post-cured.

The most void-free cases were made by these processes.

2.2.4 Raw Resin, Moderate Temperature Process

The raw resin, moderate temperature process is the same as the raw resin, fast process (section 2.2.2) except that the mold is at 400°F.

2.2.5 Pelletized Short Fiber Resin Process

The pelletized short fiber resin process was tried only one time. Pellets were preformed using 1/8-inch glass fiber filled polyimide resin made by Fiberite Corporation. These pellets were processed as in the pelletized preform, moderate temperature process (section 2.2.3). Pressure tests were unsatisfactory, so no additional parts were made by this process.

2.3 Previous Process and Pressure Tests (Contract F33615-74-C-3013)

Under the previous contract, 37 moldings were made to work out molding processes and techniques and to achieve acceptable parts. As a result of improper tooling clearance, experimental thermal processing cycles, etc., 13 moldings were not successful. The remaining 24 parts were acceptable for further use. These acceptable parts were pressure tested to evaluate structural integrity. Of the 24, only 10 withstood pressures of 2700 psi or greater in both bores, which was the final criterion established for satisfactory parts.

Pressure testing was accomplished by screwing a steel insert into the cylinder bore and pressurizing the bore with a hand pump while the unit was inside an explosion-proof box. No porting or mounting holes had, as yet, been drilled in the cases. Leakage pressures were recorded. Most failures occurred as small pinhole leaks through the cylinder walls, although cracking of the cylinder wall or leakage from the pressurized cylinder into the adjacent pin lock cylinder bore occurred in a few cases. In no case did any cylinder shatter or break into pieces. In many cases, failed parts were dissected and viewed under magnifying binoculars to determine porosity.

Table I presents the results of this initial testing process, indicating the molding process used and relevant variations.

2.4 Possible Solutions to Problems Encountered during Contract F33615-74-C-3013

A review of the process variables and molding conditions revealed several areas which could be modified to obtain a higher yield of high strength parts. Probable contributory causes of weakness and their possible solutions appear in Table II.

TABLE II

Areas of Process Modification

| Probable Contributory Causes of Weakness | Solutions |
|--|---|
| Poor fiber orientation in parts | Use full preforms; preheat correctly. |
| Stressing and cracking on eject | Apply mold release compound to cavity and punch. Hold in cavity by side retention screws. Remove punch. Remove screws. Eject. |
| Inclusion of air/porosity | Use preform; preheat and cure correctly. |
| Improper cool down | Oven cool. |
| Improper post-cure | Post-cure before cool down. |
| Improper aging | Age 1 week to 1 month before testing hydraulically. |
| Fiber length too uniform | Try mixes of resins with different fiber lengths. |
| Mold release inclusions in parts | Try using mold release compound on cylinder rods and in mold cavity on some units and try others without. |

2.5 Molding Plan

To investigate the potential solutions in Table II, a molding plan was developed as shown in Table III. It incorporates use of a one-piece preform, plus various combinations of resin mixes, ejection techniques, process timing, aging, and post-cure. The numbers of units to be molded for each set of conditions is also shown.

TABLE III

Molding Process Plan

| Number and Identification | 10 Parts No. 1 | 10 Parts No. 2 | 10 Parts No. 3 | 10 Parts No. 4 | 10 Parts No. 5 |
|---------------------------|-----------------------------|-----------------------------|----------------|----------------|----------------|
| Resin state | Preforms | Preforms | Preforms | Preforms | Preforms |
| Process timing | Slow | Fast | Best of 2 | Best of 2 | Best of 2 |
| Ejection* | 5 Low Shock 5 High Shock | 5 Low Shock 5 High Shock | Best of 2 | Best of 2 | Best of 2 |
| Resin mix | 5504 | 5504 | Mix No. 1 | Mix No. 2 | Mix No. 3 |
| Post-cure and cool | Resin Vendor | Resin Vendor | Resin Vendor | Resin Vendor | Resin Vendor |
| Aging | 2 weeks | 2 weeks | 2 weeks | 2 weeks | 2 weeks |

*High shock is associated with no mold release compound used in the cavity.

Mixing Plan:

- Mix No. 1 - 1/2 part 5504, 1/2 part 5514.
- Mix No. 2 - 1/2 part 5504, 1/2 part Fiberite PI-750.
- Mix No. 3 - 1/3 part 5504, 1/3 part 5514, 1/3 part Fiberite PI-750.

Process Timing:

- Slow Process - Enter mold at approximately 330°F.
- Fast Process - Enter mold at approximately 385°F.

NOTE: Rhodia 5504 = 65 percent 1/4 in. glass filled.
 Rhodia 5514 = 50 percent 1/8 in. glass filled.
 Fiberite PI-750 = 65 percent 1/2 in. glass filled.
 Runs 1 and 2 = Five parts with cylinder rod and mold cavity mold release compound and five parts without.

SECTION III

PREFORM FABRICATION

To make a preform with maximum density which could be heated in the LaRose dielectric heater, a single integral preform design was selected. These preforms resemble a piece of pie with the point cut off (truncated) and are approximately 1-1/4 to 1-1/2 inches thick, as shown in Figure 7. In all cases, 585 grams of resin were used in each preform.

3.1 Mold Preparation and Setup

To make this preform, the loading zone from the mold shown in Figure 3 was removed and mounted in a 150-ton laboratory press with suitable spacer blocks to raise the loading zone off the bottom plates as shown in Figure 8. Movable ram plates having the same truncated pie shape as the finished preform formed a cavity within the loading zone into which raw resin could be poured. These rams then compacted the resin when the press was energized. The heaters already present in the loading zone were energized. The top aluminum ram plate was preheated on a hot plate until loading was imminent. The bottom aluminum plate contained its own heaters. The temperatures of the loading zone and bottom plate were monitored by direct reading thermocouple monitors. The temperature of the top aluminum ram plate was monitored by pyrometer.

3.2 Resin Characteristics

3.2.1 Rhodia 5504

As shown in Table III, Rhodia 5504 polyimide resin containing 65 percent (by weight) 1/4-inch glass reinforcement fibers was selected as the prime resin. This resin was also used exclusively during contract F33615-74-C-3013.

3.2.2 Rhodia 5514

This resin, also manufactured by Rhodia, Inc., is a polyimide resin that contains 50 percent (by weight) 1/8-inch glass fibers. It was used in mixtures containing either 1/4-inch or 1/2 inch fibers or both according to the molding plan of Table III.

3.2.3 Fiberite PI-750

This polyimide resin, manufactured by Fiberite Corporation, contains 65 percent (by weight) 1/2-inch glass fibers. It was used in mixtures containing either 1/8-inch or 1/4-inch fibers or both according to the molding plan of Table III.

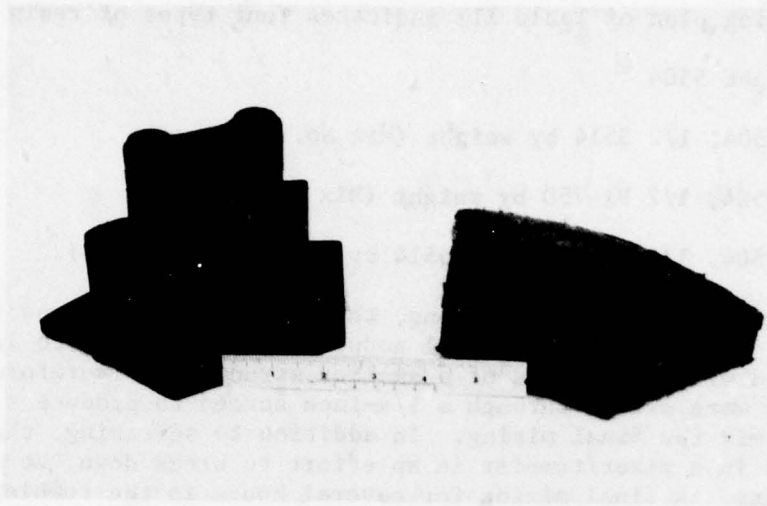


Figure 7. Integral Preform Design

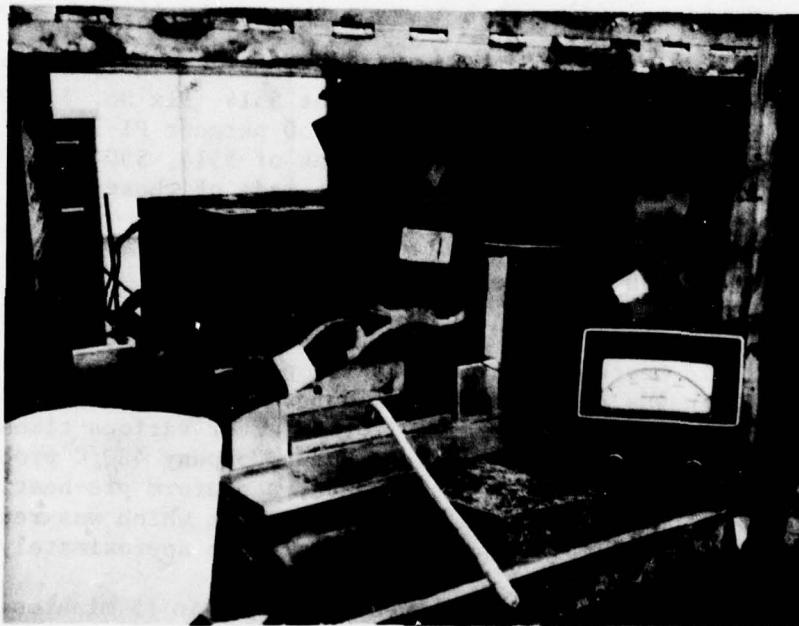


Figure 8. 150-Ton Press

3.3 Resin Mixing

The molding plan of Table III indicates four types of resin combinations:

- 1) Straight 5504
- 2) 1/2 5504, 1/2 5514 by weight (Mix No. 1)
- 3) 1/2 5504, 1/2 PI-750 by weight (Mix No. 2)
- 4) 1/3 5504, 1/3 PI-750, 1/3 5514 by weight (Mix No. 3).

During initial mixing operations, the 5514 resin was found to be not homogeneous, but occurring in small nodular form (1/4-inch to 1/2-inch flakes) mixed with quantities of a smaller structure. Therefore, all three basic resins were sifted through a 1/4-inch screen to produce a more homogeneous dry mix for final mixing. In addition to screening, the resins were tumbled in a mixer/tumbler in an effort to break down the size of the nodular flakes. A final mixing for several hours in the tumbler assured thorough blending of the different resins.

3.4 Fabrication

The preform mold described in section 3.1 was brought to 250°F and the raw resin (585 grams) was loaded. The press was closed for 3 minutes to produce a pressure of 4800 psi in the resin. After the press was opened, the preform was ejected from the bottom of the cavity (Figure 8).

Twenty-eight preforms were made with 5504 resin. Thirteen preforms were made with 50 percent 5504 and 50 percent 5514 (Mix No. 1). Thirteen preforms were made with 50 percent 5504 and 50 percent PI-750 (Mix No. 2). Thirteen preforms were made with 33.3 percent of 5514, 5504, and PI-750 (Mix No. 3). An additional 10 preforms were made of these mixes to perform dielectric heater experiments.

3.5 Dielectric Heating Experiments

Ten preforms were subjected to various heatings in a La Rose model 160B/100 dielectric heater at various heater plate spacings. In some cases, this heating was preceded by 15 minutes in a hot air oven at 250°F. Preform internal temperatures were monitored (after various times in the dielectric heater) with a Pyrometer Instrument Company 42Q/C probe type pyrometer. As a result of these experiments, a preform pre-heating cycle was established to obtain a pliant moldable preform which was ready for insertion into the final mold (internal temperature approximately 250°F):

- 1) Place preform in an open air oven at 250°F for 15 minutes.
- 2) Immediately place preform in the dielectric heater for 4 minutes using a plate spacing of 3.2 inches (dielectric heating plate current was approximately 465 milliamps).

- 3) Test preform for pliability with hands, then place in final mold. If not pliable, heat 1 additional minute. Do not place nonpliable preform in the final mold (cylinder-making pins in the mold could be damaged).

The third step is necessary, since heating repeatability between preforms was found to be somewhat random, i.e., some preforms did not heat as rapidly as others, probably due to inexact preform fabrication conditions. Preform internal temperatures were not measured inside the dielectric heater since it is a high frequency, high voltage RF generator.

3.6 Storage of Preforms

Preforms were marked and sealed in plastic bags and stored in a refrigerator at a temperature of approximately 10°F until required for molding.

SECTION IV

MOLDING PROCESS

4.1 Mold Modifications

Modifications to the mold were minimal. After using the loading zone to fabricate preforms, it was only necessary to reassemble the loading zone and cover plate to the cavity. The cavity was modified by adding four 3/8-inch heat-treated cap screws at its top, as shown in Figure 4. These screws can be advanced so that small indentations are molded into the box portion of the actuator case. Consequently, the punch can be removed without pulling the case out of the cavity. When the case is ejected from the cavity, the screws are first backed out. In this way, mold release compound can be copiously applied on both the punch and in the cavity so that minimal strains are experienced during part removal. The small indentations caused by the screws affect esthetics only.

A holding fixture was made (Figure 9) to aid in removal of the thread-making inserts. High temperature molding plaster was used to form the cavity shown.

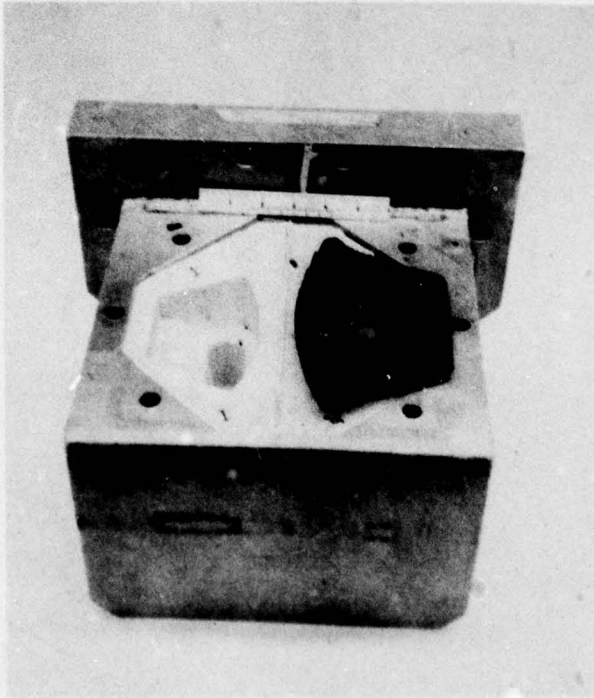


Figure 9. Holding Fixture

4.2 Process Description and Results

Basically, the molding plan described in Table III was followed as outlined in section 2.5. All parts were post-cured for 24 hours at 250°F in an open air oven, since Table I results showed better pressure test results than units post-cured at higher temperatures. Section V lists each unit and pertinent remarks.

During molding of the 23rd part, the mold was damaged. The center screw-making insert, which normally attaches to the punch and is unscrewed from the finished part, fell off while the punch was travelling through the loading zone. This large steel insert fell into one of the cylinder bores in the cavity and the cylinder-making rods on the punch closed on it without the press operator's knowledge. A large gouge occurred in the cavity, and the rod was severely bent. After removal of the mold from the press, the gouge was filled with weld metal and ground and polished to shape. The cylinder-making rod was replaced. Molding operations were then resumed.

4.2.1 100 Percent 5504 Resin, Slow Process

This process consisted of first heating the preforms as described in section 3.5. The preform was then inserted in the loading cavity with the mold temperature at 330°F. The press was closed to 45 to 50 tons force (a pressure of 4000 to 4444 psi). After 5 minutes, mold heat was increased to full capability until a mold temperature of 400°F was attained, at which time the punch was partially removed and all heat was turned off. When the mold temperature reached 300°F (approximately 1 hour later), the part was ejected, and the cycle was repeated.

A total of 13 parts were made by this process, 11 were satisfactory for testing. Of the 13, seven units used a liberal quantity of mold release compound on both punch and cavity. The first part made used mold release compound and was dissected, polished, and examined under a magnifier for evidence of porosity. None was found. The remaining six units were molded with no mold release compound used except on the three thread-making inserts.

4.2.2 100 Percent 5504 Resin, Fast Process

This process was essentially identical to that of section 4.2.1 except that all molding operations were performed at a constant mold temperature of 385°F. Constant temperature enabled reloading as soon as the mold was refurbished. A total of 12 parts were made by this method.

The first part made by this method was also dissected, examined for porosity, and found to be of good density with only a trace of porosity near the end of one cylinder. Again, molding both with and without mold release compound was evaluated.

4.2.3 Process Selection

After fabrication of the two groups of parts, the parts molded as described in sections 4.2.1 and 4.2.2 were hydraulically pressure tested to determine which molding process should be used for the remaining parts. Section 5.0 shows that the highest failure pressures occurred for units molded by the slow process of section 4.2.1. The average failure pressure for cylinders molded by the fast method was 1505 psi versus 3147 psi for the slow process. On this basis, the slow process was selected. Since it was not evident that the use of mold release compound on both punch and cavity walls had any deleterious effects, mold release was to be used on both punch and cavity walls, since ejection of the part was noticeably easier. All parts thereafter made with mixes of different fiber lengths were molded by the slow process using mold release compound on both punch and cavity walls. A post-cure of 24 hours at 250°F in an air circulating oven and a 2-week wait before testing was applied to all subsequent parts.

4.2.4 Mix No. 1

Molding continued using Mix No. 1 preforms (1/2 5504 and 1/2 5514 by weight), using methods as selected in section 4.2.3. Twelve aft cases were molded using Mix No. 1. No difficulty was experienced either in dielectric preheating or in molding. Pressure test results are discussed in section V. Dissection of a part revealed good density and no porosity; however, blisters appeared in the cylinder bores. These blisters were approximately 1/16 inch to 1/8 inch in diameter and appeared to be made of pure resin.

4.2.5 Mix No. 2

Twelve cases were molded with preforms made of Mix No. 2 (1/2 5504 and 1/2 PI-750). The methods described in section 4.2.3 were also used. The long 1/2-inch fibers of PI-750 compound in the preforms presented no additional preheating problems. The polyimide PI-750, made by Fiberite Corporation, appeared to be mixable with the Rhodia 5504 polyimide resin, with no apparent mechanical separation or adverse reaction. Pressure test results are discussed in section V. Dissection of a part revealed a solid void-free part with no blistering and a good cylinder finish. Some of the long 1/2-inch fibers could be seen just below the resin surface. No blistering occurred.

4.2.6 Mix No. 3

Thirteen cases were molded with preforms made of Mix No. 3 (1/3 5504, 1/3 PI-750, and 1/3 5514). Again, there was no preheating problem, and resin components were mixable with no adverse effects. Pressure test results are discussed in section V. Dissection of a part revealed porosity in the end of the cylinders. No blisters were present.

SECTION V

HYDRAULIC PRESSURE TESTING RESULTS

Table IV presents the results of the hydraulic pressure tests of the molded aft case parts. The part numbers used (in the left-hand column) carry individual designations:

- I = All parts made of Rhodia 5504 resin
- II = Mix No. 1 (all parts made of 50 percent 5504 and 50 percent 5514)
- III = Mix No. 2 (all parts made of 50 percent 5504 and 50 percent Fiberite PI-750)
- IV = Mix No. 3 (all parts made of equal quantities of 5504, 5514, and PI-750).

The arabic numeral in each part number of Table IV is the order of fabrication within each resin mix. Letters S or F indicate use of the slow process (section 4.2.1) or the fast process (section 4.2.2).

Pressure testing was accomplished by pressurizing each bore through a steel threaded plug which was screwed into each cylinder bore separately (first one bore, than the other). The plug used the molded-in O-ring seat and its O-ring to effect a seal. A hydraulic hand pump with a 0 to 5000 psi guage was used for pressurization. MIL-H-5606 fluid was used as the pressurizing fluid.

If nominal system pressure is assumed to be 1925 psi (the pressure which generated the required 400 in-lb of actuator torque during contract F33615-74-C-3013), the proof pressure required by MIL-H-25475B is 2888 psi.

5.1 5504 Slow Process Results

Parts numbered I-1-S through I-10-S and parts I-23-S through I-25-S were made using Rhodia 5504 resin preforms according to the process outlined in section 4.2.1. The average failure pressure for the 22 bores tested was 3147 psi. Four bores were not available for pressure testing, since they were either dissected to check porosity (none was found) or were damaged in molding. No appreciable increase in bore strength over the 2926 psi average of all processes listed in Table I is apparent. Only 4 of the 11 parts would have passed the 2888 psi proof pressure criteria which is consistent with the low yield derived during the previous contract.

TABLE IV
Molding Process and Pressure Test Results (Summary)

| Part No. | Resin | Molding Process | | | | | Pressure (psi) | | Remarks and Molding Press Force |
|--------------------|-------|-----------------|------|---------|------------|--------|----------------|--|---------------------------------|
| | | Fast | Slow | Release | No Release | Bore A | Bore B | | |
| | | | | | | | | | |
| I-1-S 10-5-76 | 5504 | | X | X | | - | - | Cut part in half and sanded smooth for inspection. Part looked good and dense. 45 ton. | |
| I-2-S 10-5-76 | 5504 | | X | X | | 4250 | 1700 | The safety light was tripped and broke the circuit. Pressure was reapplied immediately. 45 ton. | |
| I-3-S 10-6-76 | 5504 | | X | X | | 3300 | 3350 | | |
| I-4-S 10-6-76 | 5504 | | X | X | | 4900 | 1400 | Upon ejection, the part moved up 1/2 hold-in screw width. Safety light was tripped twice during cycle. 45 ton. | |
| I-5-S 10-6-76 | 5504 | | X | X | | 3400 | 4200 | | |
| I-6-S 10-7-76 | 5504 | | X | X | | 3800 | 2000 | | |
| I-7-S 10-8-76 | 5504 | | X | | X | 3600 | 4300 | Part looks OK except two or three slight sticking marks where part stuck to mold. 48 ton. | |
| I-8-S 10-8-76 | 5504 | | X | | X | 2400 | 2200 | Pins bent - Center insert hole chewed up slightly because two bottom threads on center insert were damaged. Part stuck in two or three places but came out OK. 48 ton. | |
| I-9-S 10-8-76 | 5504 | | X | | X | 3900 | 3800 | Pins bent slightly from I-8-S. 50 ton. | |
| I-10-S 10-12-76 | 5504 | | X | | X | 2700 | 2600 | OK but some scratch marks on outside of part. 50 ton. | |
| I-11-F 10-13-76 | 5504 | X | | | X | - | - | Cut part in half and sanded smooth for inspection. Part looked good and dense with only a trace of porosity. 50 ton. | |
| I-12-F 10-13-76 | 5504 | X | | | X | - | - | Not good part - the bottom of the two cylinders (outside) did not fill out. Possibly the preform was too far advanced. 50 ton. | |

TABLE IV (Cont)

| Part No. | Molding Process | | | | | Pressure (psi) | | Remarks and Molding Press Force |
|----------|-----------------|------|------|---------|------------|----------------|--------|--|
| | Resin | Fast | Slow | Release | No Release | Bore A | Bore B | |
| I-13-F | 5504 | X | | X | | 2700 | 3400 | 50 ton. |
| 10-13-16 | | | | | | | | |
| I-14-F | 5504 | X | | X | | 800 | 1700 | 50 ton. |
| 10-14-16 | | | | | | | | |
| I-15-F | 5504 | X | | X | | 2100 | 1200 | 50 ton. |
| 10-14-76 | | | | | | | | |
| I-16-F | 5504 | X | | X | | 1600 | 1900 | 50 ton. |
| 10-14-76 | | | | | | | | |
| I-17-F | 5504 | X | | X | | 800 | 900 | 50 ton. |
| 10-14-76 | | | | | | | | |
| I-18-F | 5504 | X | | | X | 1200 | 900 | 50 ton. |
| 10-14-76 | | | | | | | | |
| I-19-F | 5504 | X | | | X | 900 | 800 | 50 ton. |
| 10-15-76 | | | | | | | | |
| I-20-F | 5504 | X | | | X | 1100 | - | Leaks A to B. 50 ton. |
| 10-15-76 | | | | | | | | |
| I-21-F | 5504 | X | | | X | 1600 | 1800 | 50 ton. |
| 10-15-76 | | | | | | | | |
| I-22-F | 5504 | X | | | X | 2100 | 1100 | 50 ton. |
| 10-15-76 | | | | | | | | |
| I-23-S | 5504 | | X | | X | - | - | Left pin bent badly. Center insert came off and was pushed down into the left pin area. Replaced bent pin. Filled gouged places with welding material and reworked area damaged. 50 ton. |
| 10-18-76 | | | | | | | | |
| I-24-S | 5504 | | X | | X | 2320 | 3700 | Part OK. 50 ton. |
| 11-3-76 | | | | | | | | |
| I-25-S | 5504 | | X | X | X | 3020 | 2400 | 50 ton. |
| 11-17-76 | | | | | | | | |
| II-1-S | MIX I | | X | X | X | 2500 | 1580 | 50 ton applied. |
| 11-3-76 | | | | | | | | |

TABLE IV (Cont)

| Part No. | Molding Process | | | | Pressure (psi) | | Remarks and Molding Press Force | |
|---------------------|-----------------|------|------|---------|----------------|--------|---------------------------------|---|
| | Resin | Fast | Slow | Release | No Release | Bore A | | Bore B |
| II-2-S 11-4-76 | MIX I | | X | X | | 2720 | 2700 | 50 ton. |
| II-3-S 11-4-76 | MIX I | | X | X | | 2320 | 2750 | 50 ton. |
| II-4-S | MIX I | | X | X | | 3350 | 1700 | 50 ton. |
| II-5-S 11-5-76 | MIX I | | X | X | | 3180 | 2500 | Dissected. Cylinder bores have 1/16 inch to 1/8 inch blisters. Some porosity. 50 ton. |
| II-6-S 11-6-76 | MIX I | | X | X | | 2050 | 2280 | 50 ton. |
| II-7-S 11-8-76 | MIX I | | X | X | | 1400 | 1980 | 50 ton. |
| II-8-S 11-8-76 | MIX I | | X | X | | 3200 | 3020 | 50 ton. |
| II-9-S 11-8-76 | MIX I | | X | X | | 2200 | 1980 | 50 ton. |
| II-10-S 11-8-76 | MIX I | | X | X | | 3500 | 3480 | 50 ton. |
| II-11-S 11-16-76 | MIX I | | X | X | | 2850 | 3100 | 50 ton. |
| II-12-S 11-17-76 | MIX I | | X | X | | 2480 | 3580 | 50 ton. |
| III-1-S 11-9-76 | MIX II | | X | X | | 4950 | 4200 | 50 ton. |
| III-2-S 11-9-76 | MIX II | | X | X | | 3150 | 4300 | 50 ton. |
| III-3-S 11-9-76 | MIX II | | X | X | | 4400 | 3980 | 50 ton. |
| III-4-S 11-9-76 | MIX II | | X | X | | 4000 | 2950 | 50 ton applied. |

TABLE IV (Cont)

| Part No. | Molding Process | | | | | Pressure (psi) | | Remarks and Molding Press Force |
|----------------------|-----------------|------|------|---------|------------|----------------|--------|---|
| | Resin | Fast | Slow | Release | No Release | Bore A | Bore B | |
| III-5-S 11-10-76 | MIX II | | X | X | | 3400 | 3350 | 50 ton. |
| III-6-S 11-10-76 | MIX II | | X | X | | 2400 | 3520 | Dissected after test. No porosity. Very dense. Good finish. No blisters. Some fibers visible under gel coat in bores. 50 ton. |
| III-7-S 11-10-76 | MIX II | | X | X | | 3620 | 3600 | 50 ton. |
| III-8-S 11-10-76 | MIX II | | X | X | | 3700 | 3400 | 50 ton. |
| III-9-S 11-10-76 | MIX II | | X | X | | 4200 | 4900 | 50 ton. |
| III-10-S 11-11-76 | MIX II | | X | X | | 4100 | 3480 | 50 ton. |
| III-11-S 11-16-76 | MIX II | | X | X | | 4250 | 4880 | 50 ton. |
| III-12-S 11-16-76 | MIX II | | X | X | | 4300 | 3300 | 50 ton. |
| IV-1-S 11-11-76 | MIX III | | X | X | | 3550 | 4020 | 50 ton. |
| IV-2-S 11-11-76 | MIX III | | X | X | | 4400 | 3300 | Dissected after test. Some porosity. No blisters. 50 ton. |
| IV-3-S 11-11-76 | MIX III | | X | X | | 2420 | 1800 | 50 ton. |
| IV-4-S 11-11-76 | MIX III | | X | X | | 3000 | 2600 | 50 ton. |
| IV-5-S 11-12-76 | MIX III | | X | X | | - | - | Lost pressure in the press. Part was no good. |
| IV-6-S 11-12-76 | MIX III | | X | X | | 3000 | 3720 | 50 ton. |

TABLE IV (Cont)

| Part No. | Resin | Molding Process | | | No Release | Pressure (psi) | | Remarks and Molding Press Force |
|---------------------|---------|-----------------|------|---------|------------|----------------|--------|---------------------------------|
| | | Fast | Slow | Release | | Bore A | Bore B | |
| IV-7-S 11-12-76 | MIX III | | X | X | | 4100 | 3480 | 50 ton applied. |
| IV-8-S 11-12-76 | MIX III | | X | X | | 2200 | 2200 | 50 ton. |
| IV-9-S 11-12-76 | MIX III | | X | X | | 2620 | 2300 | 50 ton. |
| IV-10-S 11-15-76 | MIX III | | X | X | | 2820 | 3820 | 50 ton. |
| IV-11-S 11-15-76 | MIX III | | X | X | | 2650 | 3020 | 50 ton. |
| IV-12-S 11-15-76 | MIX III | | X | X | | 2950 | 4500 | 50 ton. |
| IV-13-S 11-17-76 | MIX III | | X | X | | 3200 | 4400 | 50 ton. |

The use or non-use of mold release compound (Mold-Wiz, AXEL Inc., Brooklyn, N.Y.) had little discernable effect on the cylinder strength, although three cylinders failed over 4000 psi using mold release versus one over 4000 psi for the non-use case.

5.2 5504 Fast Process Results

Parts numbered I-11-F through I-22-F were made using Rhodia 5504 resin preforms according to the process outlined in section 4.2.2. The average failure pressure for the 19 bores was 1505 psi. One part, I-20-F, was tested in only one bore, since bore A leaked into bore B. Again, the use or non-use of mold release compound had little discernable effect on cylinder strength. The 1505 psi is significantly inferior to both the averages of Table I (2926 psi) and to the strength of the slow process samples (3147 psi).

The low average leak pressure of 1505 psi for this fast process eliminated it from further consideration. Consequently, all parts made from resin mixes were made using the slow process described in section 4.2.1. Mold release compound was also used in both the cavity and on the punch.

5.3 Mix No. 1

Parts numbered II-1-S through II-12-S were made using 50 percent Rhodia 5504 and 50 percent Rhodia 5514 and were molded using the slow process described in section 4.2.1. The average failure pressure for the 24 bores made in this way was 2600 psi. This failure pressure is inferior to both the Table I average (2926 psi) and to the 3147 psi average of the Rhodia 5504 parts made via the slow process. Only two of the 12 Mix No. 1 parts would have passed the 2888 psi proof pressure criterion of section V.

A dissection test showed good density, so no clue to the low leak pressure is evident except for the blisters noted in section 4.2.4.

5.4 Mix No. 2

Parts numbered III-1-S through III-12-S were made using 50 percent Rhodia 5504 and 50 percent Fiberite PI-750. Average failure pressure for the 24 bores made in this way was 3847 psi. This value is significantly superior to the Table I average of 2926 psi and higher than those for any of the other mixes or processes investigated. Also, only one of these 12 parts would have been rejected using the 2888 psi proof pressure criterion, and this rejected part would have passed one bore at 3520 psi. This part was dissected after pressure test and found to be very dense, with no apparent porosity.

Table V lists results of readings taken with a three-prong hole micrometer after the pressure tests (after number III-6-S had been dissected). The maximum spread measured for all 22 bores is 0.0020 inch for bore A and 0.0021 inch for bore B. Also, both inboard and outboard bearings were trial fitted into their respective races of all 11 parts. All races fit well.

TABLE V

Mix No. 2 Cylinder
Bore Measurements

| | Bore A | Bore B |
|----------|------------|--------|
| III-1-S | 0.5034 | 0.5009 |
| III-2-S | 0.5032 | 0.5016 |
| III-3-S | 0.5045 | 0.5024 |
| III-4-S | 0.5042 | 0.5017 |
| III-5-S | 0.5040 | 0.5012 |
| III-6-S | - Cut Up - | |
| III-7-S | 0.5030 | 0.5015 |
| III-8-S | 0.5047 | 0.5027 |
| III-9-S | 0.5029 | 0.5008 |
| III-10-S | 0.5028 | 0.5023 |
| III-11-S | 0.5027 | 0.5006 |
| III-12-S | 0.5045 | 0.5014 |

5.5 Mix No. 3

Parts numbered IV-1-S through IV-13-S were made using equal parts of Rhodia 5504, Rhodia 5514, and Fiberite PI-750. The average failure pressure for the 24 bores was 3170 psi. One part, IV-5-S, was not a complete part, since the press lost pressure during the first part of the cure cycle. Dissection of part number IV-2-S after pressure test revealed a small amount of porosity in the cylinder ends and no blisters. Only six of the 12 parts molded would have passed the 2888 psi proof pressure criterion.

SECTION VI

SUMMARY

A total of 57 actuator aft cases were pressure tested after molding via various compression molding processes and resin mixtures. A process which loads preformed resin at a moderate temperature (330°F), and a resin mixture (Mix No. 2) consisting of two different polyimide resins were used to obtain parts which show a significant increase in strength. Against a proof pressure of 2888 psi (the target proof pressure for this actuator), 11 of the 12 parts made by this process and resin would have been acceptable prior to drilling and porting of the cases. This acceptability represents a significant increase in the yield of acceptable parts over the approximately 35 percent obtained during actuator development under contract F33615-74-C-3013.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

The objective of this task - to develop processes and procedures for molding hydraulic cylinder cases to produce a consistent, high yield of high strength useable parts - was achieved based on conclusions drawn from the effort performed.

- 1) The process described in section 4.2.1 is the best process of any tried up to this point. It results in or aids markedly in obtaining consistently nonporous parts.
- 2) A mixture of two polyimide resins, 50 percent Rhodia 5504 (1/4 inch glass fiber) and 50 percent Fiberite PI-750 (1/2 inch fibers) by weight was the best material tried during the investigation.
- 3) Full preforms are highly desirable, if not necessary, for obtaining dense, nonporous parts. They also greatly facilitate expeditious loading during the molding operation.
- 4) The use of mold release compound in the cavity, as well as on the punch, is recommended, together with a means for positively locking the cured part in the mold during punch withdrawal.
- 5) Use of the methods described in items 1 through 4 made possible a significant increase in the yield of pressure-tight parts, since 11 of 12 parts made by these methods passed the 2888 psi proof pressure test in both cylinder bores, and only one bore of the 24 failed this criterion. The average failure pressure for the 24 bores was 3847 psi.

The following recommendations are made:

- 1) To further optimize weight, performance, and cost elements, further work should be accomplished in the optimization of resin-to-fiber weight ratios and fiber lengths. It is obvious that an effect exists; however, no attempt has been made to optimize these parameters.
- 2) Further work should be accomplished to investigate the effect on yield of good parts of loading the preforms at moderate temperature and then a) quickly increasing mold temperature and b) quickly cooling the mold to speed up the process.

- 3) The effects of drilling and porting the parts on the final yield of good parts should be ascertained (drilling and porting is required in an actual actuator design).
- 4) Test specimens molded by different processes and resins should be fabricated and physically tested (rather than pressure tested) to determine whether other actuator parts, such as the shaft and forward case which do not contain high pressure fluid, can be made by the cheaper, faster processes than that of section 4.2.1 in the report.
- 5) The knowledge gained by the recommended effort outlined in items 1 through 4 could then be applied to optimize the weight, performance, and cost of the actuator.