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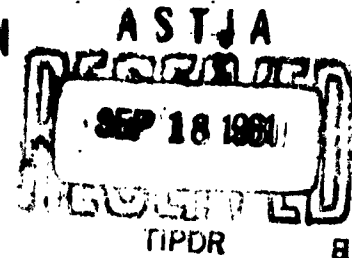
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NAVWEPS REPORT 7051
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A NEW APPROACH TO PLASTIC-MANDREL FABRICATION

By

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ABSTRACT. This report describes the development of an economical process for fabricating plastic mandrels for use in solid-propellant rocket motors.

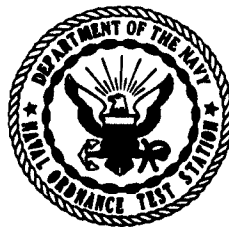
Several different types of mandrels were produced from plastic materials for new solid-propellant rocket motors. Tests were performed to determine the shrinkage of the plastic mandrels, tensile strength of various formulations of plastic, surface roughness of plastic mandrels as compared to the master mandrels, thermal conductivities of the plastic formulations, and bond strengths of a silicone-elastomer coating as a mold-release agent on plastic mandrels.

Satisfactory mandrels for motors up to 24 inches in diameter and 84 inches in length can be made.

Where several mandrels are required, producing plastic mandrels is economically feasible.

A method for coating plastic and fabricated aluminum mandrels, not involving the use of any materials leaving a residual grease or wax coating, has been developed.

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INTRODUCTION

This report describes recent progress in the development of an economical and rapid process for fabricating plastic mandrels for use in solid-propellant rocket motors. The process was described briefly in NOTS TP 2307. The most effective method found is described.

A master mandrel, or pattern, is fabricated from aluminum, steel, an epoxy resin with aluminum powder as filler, wood, or any nonporous material. The pattern is placed in a suitable mold, and a silicone rubber compound of the room-temperature-vulcanizing (RTV) type is cast around it. After the silicone rubber is cured, the pattern is removed, leaving a female reproduction, or chase,¹ of the master pattern. This cavity is then cast with an epoxy-aluminum mixture. After being cured, the epoxy-aluminum mandrel, or core, is removed from the mold and post-cured.

The epoxy-aluminum mandrel is painted, dipped, or sprayed with two primers and dried. A coating of RTV rubber is then applied over the entire surface of the mandrel and cured. The plastic mandrel is now ready for use in forming the center cavity of the propellant in a rocket motor.

Several advantages are realized using this system, as compared to machining or extruding mandrels. The primary advantages are low cost, short fabrication time, and light weight.

As compared to other techniques of making plastic mandrels, the reproduction of the pattern by the RTV rubber is very good, since no mold-release agents are required in making the pattern or the female mold. The plastic mandrel with the RTV coating requires no release agent and can be used many times before recoating with fresh RTV is necessary. Propellants have been cast using the same mandrel many times without damage to the silicone-rubber coating. Repairing scratches in the silicone coating is much simpler than repairing a Teflon coating on a metal mandrel.

Using this process, only one pattern is required, since the first reproductions may be used as master mandrel patterns to cast additional chases.

Another advantage of plastic mandrels over metal mandrels in development work is the fact that plastic reproductions can be machined, or modified, to give a new design without ruining the original pattern.

¹The main body of the mold that contains the molding cavity, the guide pins, etc.

Mandrels fabricated from aluminum tubes may warp at the high temperatures required for Teflon coating. Using cured RTV rubber as the release agent in casting propellant eliminates the need for excessive heating.

The silicone rubber chase may also be used for casting mandrels made of low-melting alloys.

DESCRIPTION OF MATERIALS AND APPARATUS

The silicone rubber currently in use is RTV-60, which is supplied by the General Electric Company. If post-cured properly, it may be used at temperatures above 400°F. The rubber is self-releasing from most surfaces. One exception is that the uncured liquid prepolymer will bond to the cured RTV-60.

RTV-88, also supplied by General Electric, has been used in mandrel coatings. It is similar to RTV-60 but has a higher viscosity.

The primers used are 81822 and XS-4004. The silicone fluid SF-69 is used as a viscosity adjuster in the RTV-60.

Thermolite 12 is used as the catalyst for the RTV-60. Depending on the desired pot life, 1/10 to 1% is used.

The Epon epoxy resin series is used almost exclusively as the binder for the plastic mandrels. Epon 828, 815, and 562 were used with good results; however, other equivalent epoxies would be suitable.

Hardner 951 is used with the epoxies. Approximately 10 parts per hundred of resin is used, depending on the amount of prepolymer being mixed. With small mandrels, a curing time of about 4 hours at room temperature is required. At 110°F, a curing time of 2 hours is adequate.

Atomized aluminum powder is used as the filler for most formulations. Other materials were evaluated, with varying degrees of success. The use of phenolic microballoons in an epoxy base gave exceedingly light mandrels, but these mandrels were extremely brittle. The same was true of epoxies filled with carbon black. Teflon-filled epoxies were strong, but the finely divided Teflon is very expensive.

Mixing of the RTV rubbers with catalyst may be accomplished in various types of mixers. Currently, a Lightnin air-driven mixer, a Cowles Dissolver, or a vertical propellant mixer is used. A photograph of a 25-gallon vertical propellant mixer is shown in Fig. 1.

The epoxy resin and atomized aluminum powder were mixed in a similar manner to the RTV rubber. The catalyst is usually mixed into the epoxy-aluminum mixture with a Lightnin mixer or the Cowles Dissolver. Since the pot life in a large batch of catalyzed epoxy is unreliable, the expensive propellant mixers are not used.

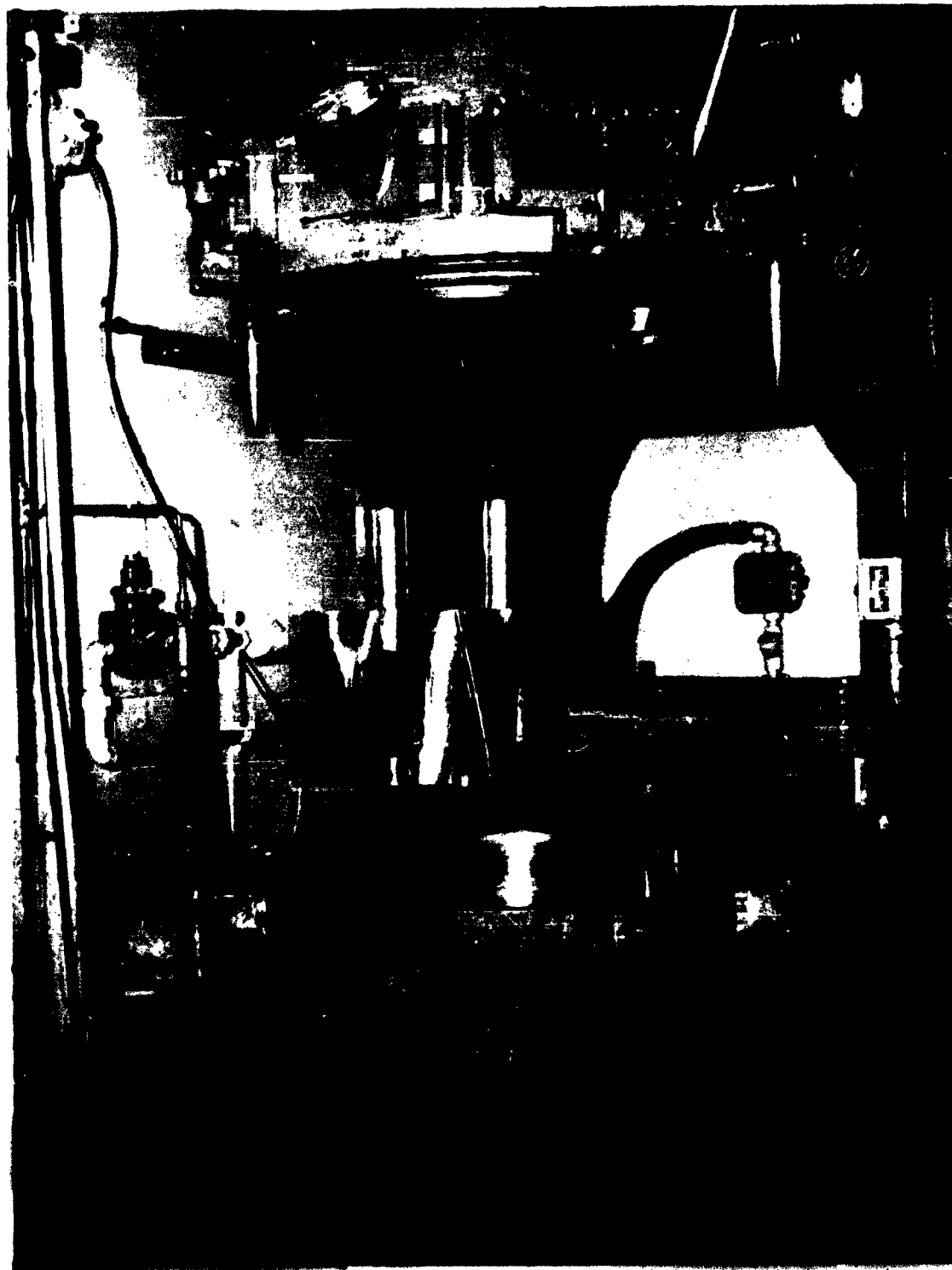


FIG. 1. Twenty-Five-Gallon Vertical Propellant Mixer.

DESCRIPTION OF PROCEDURE

Only one pattern is required to fabricate many plastic mandrels. This pattern may be made of almost any suitable material, the only requirement being that if a porous material is used, the surface should be sealed with wax or a similar material. In the past, aluminum, steel, epoxy-aluminum, and wooden patterns were used. The aluminum and steel patterns need not be Teflon-coated. The epoxy-aluminum patterns require no release agent. Wooden patterns are hand-rubbed with wax to prevent the silicone-rubber chase from mechanically bonding to the relatively porous wood surface.

The cylindrical metal tube (Fig. 2), in which the chase is molded, is designed so that the minimum wall thickness of the silicone rubber

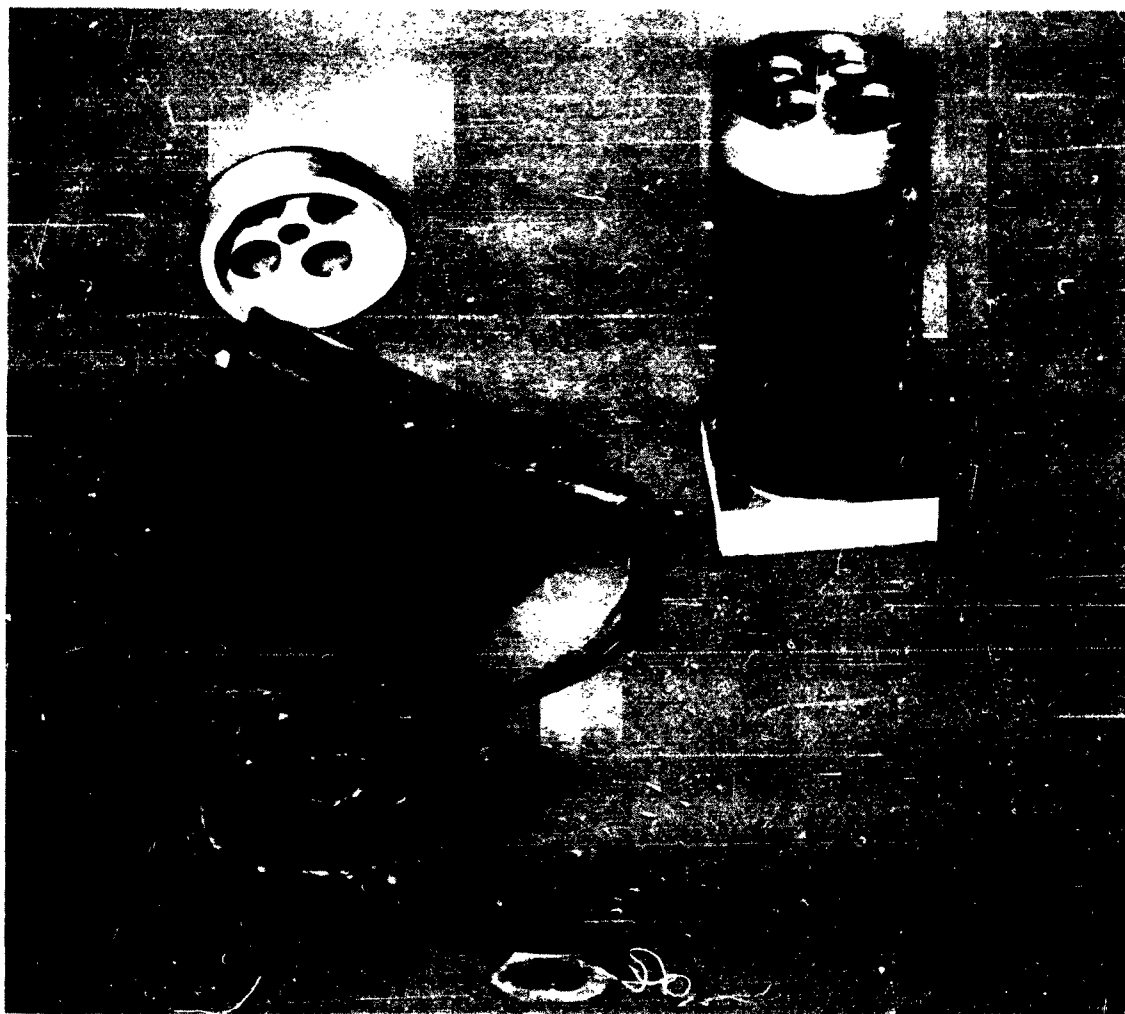


FIG. 2. Alignment Fixtures and Empty Mold.

is at least 1/4 inch. If very large mandrels are to be produced, the mold should be designed to follow the contours of the mandrel pattern and, thereby, economize on the amount of silicone rubber required.

The cylindrical metal mold surface is degreased by cleaning it thoroughly with trichloroethylene and drying it at room temperature. It is then painted with 81822 primer and allowed to stand overnight. (Consult Table 1 for complete raw material list.) Then it is coated with XS-4004 primer and dried for at least 2 hours at room temperature. After the silicone prepolymer has been cast into the cylindrical metal tube and cured, the rubber will be case-bonded to the chase, forming the internal cavity. This is done to keep the mold from constricting or warping as a result of shrinkage of the rubber.

TABLE 1. RAW MATERIALS AND THEIR SUPPLIERS

Material	Supplier
81822 primer	General Electric Co.
XS-4004 primer	General Electric Co.
RTV-60 silicone rubber	General Electric Co.
Thermolite 12	Metal & Thermit Corp.
SF-69 silicone fluid	General Electric Co.
RTV-88 silicone rubber	General Electric Co.
Epon 828	Shell Chemical Corp.
Epon 815	Shell Chemical Corp.
Epon 562	Shell Chemical Corp.
Hardner 951	Furane Plastics Corp.
Alcoa 123	Aluminum Company of America
Devcon B	Devcon Corp.
Hardner B	Devcon Corp.
RTV-20 silicone rubber	General Electric Co.

The pattern is then positioned in the cylindrical metal tube by using a suitable alignment fixture. A typical alignment assembly is shown in the upper right hand corner, and the components are shown in the lower left corner of Fig. 2. The fixture is required only to center the pattern and regulate the length of the chase.

The proper amount of RTV-60, or equivalent, is weighed out along with the Thermolite 12 catalyst. The quantity of Thermolite 12 used will determine pot life. After being mixed thoroughly, this catalyzed RTV rubber is cast under vacuum into the chase. An easier casting procedure was developed so that vacuum casting is not necessary. This technique involves brushing a coat of RTV rubber on the clean unprimed pattern before inserting it into the metal tube. The remainder of the RTV is then cast around the pattern. This procedure prevents air bubbles from collecting at the interface between the pattern and the chase and assures that the entire surface of the pattern is wetted by the uncured rubber. This procedure is less desirable than vacuum casting because bubbles may form in the body of the chase.

The chase is then allowed to cure at room temperature for 72 hours. If the chase is to be used at elevated temperatures, it is post-cured at temperatures that are increased incrementally (50 to 100°F increments above 250°F) until it has been post-cured at a temperature higher than the desired service temperature.

The pattern may be removed from the chase either by hand or by a hydraulic jack.

The epoxy resin and aluminum for the mandrel are weighed and mixed. The proper amount of catalyst is then added and mixed into the epoxy-aluminum mixture. Typical formulations and corresponding physical properties may be found in Table 2. This mixture is then degassed as rapidly as possible in a vacuum bell. A metal stud smaller in diameter than the central hub of the mandrel is inserted into the top through the chase and into the bottom plate of the alignment fixture. The epoxy-aluminum slurry is then cast around it. Experience has shown that vacuum casting is not necessary. After the plastic is cured at room temperature, the alignment fixture is opened and the plastic mandrel removed from the mold by pulling on the locating pin, which is now part of the plastic mandrel as a metal insert. Several alternate procedures have been devised, one of which allows production of a plastic mandrel with any desired internal thread cast into the epoxy-aluminum. Internal threads of epoxy-aluminum are sufficiently strong for most applications.

TABLE 2. EPOXY FORMULATIONS AND THEIR PHYSICAL PROPERTIES

Formulation no.	Ingredients, %							Physical properties	
	Epon 815	Epon 828	Epon 526	Alcoa 123	Hardner 951	Devcon B	Hardner B	Tensile strength, psi	Elongation, %
1	46.5	.....	.....	50.0	3.3	.....	.....	5,337	5.9
2	37.4	.....	.....	60.0	2.6	.....	.....	4,170	5.3
3	28.0	.....	.....	70.0	2.0	.....	.....	4,244	5.4
4	.....	36.7	10.0	50.0	3.3	.....	.....	2,876	3.2
5	.....	27.4	10.0	60.0	2.6	.....	.....	2,975	3.8
6	.....	22.7	10.0	65.0	2.3	.....	.....	5,321	.....
7	36.7	.....	10.0	50.0	3.3	.....	.....	4,712	6.5
8	27.4	.....	10.0	60.0	2.6	.....	.....	3,977	6.2
9	18.0	.....	10.0	70.0	2.0	.....	.....	5,263	7.4
10	.....	.....	.....	.....	.....	90.0	10.0	2,065	3.9

Upon removal of the plastic mandrel from the chase, the mandrel is painted, or sprayed, with primers 81822 and XS-4004 in the same manner as described for the priming of the cylindrical tube walls. This is necessary since the RTV rubber will not bond to the epoxy without a primer coat.

The mandrel is then coated with a mixture of catalyzed RTV-60 and SF-69. This may be coated with a brush or sprayed. In Fig. 3, the coating is being applied onto the primed plastic surface with a brush. After the coating is cured at room temperature, it may be post-cured



FIG. 3. Plastic Mandrel Being Coated With Silicone Rubber.

at temperatures above the desired service temperature. The thin coating of RTV rubber than acts as a mold-release agent when the mandrel is used for forming the cast propellant.

EXPERIMENTAL DATA

Experience indicates RTV-60 is superior to RTV-20 for making plastic-mandrel molds. It has a much higher tear strength and hardness, which allows each mold to produce a greater number of mandrels before patching is necessary. Most molds for small mandrels will produce at least 20 mandrels before mold damage is evident. Two molds of a mandrel 2.5 inches in diameter and 70 inches long have produced over 30 plastic reproductions each, while at a temperature of 110°F to speed production. Small mandrels cast in RTV-20 molds are larger in all

dimensions than the pattern. This is due to compression of the soft RTV-20. Identical mandrels cast in RTV-60 molds are smaller in all dimensions than the pattern because of shrinkage of the epoxy-aluminum formulations used. Figure 4 compares the dimensions of an aluminum mandrel pattern with the dimensions of mandrels cast in RTV-60 and RTV-20 molds made from the pattern. Figure 5 compares the dimensions of a plastic mandrel for use in forming the perforation of a 24-inch diameter motor with the dimensions of the aluminum pattern from which it was made.

Many different formulations of plastic were used. Some of the resins evaluated were Epon 828, 815, and 562, Devcon, and various polyesters. Aluminum Teflon, phenolic microballoons, and carbon black were evaluated as fillers. The best formulations appeared to be mixtures of epoxies, since higher elongations were obtained at approximately the same level of tensile strength were obtained than with the individual resins. The physical properties desired are from 4,000 to 5,000 psi tensile and 5 to 10% elongation. Fairly high concentrations of aluminum are used to hold shrinkage to a minimum, as well as to cut costs and increase the thermal conductivity of the plastic mandrels.

Mandrels cast of Devcon B containing 80%, by weight, of finely divided steel had only one-half, or less, the tensile strength of the epoxy-aluminum mixtures tested.

	PATTERN VARIATION, IN.		PATTERN VARIATION, IN.	
	A	B	A	B
MANDREL PATTERN (AL)	0.191	0	4.734	0
EPOXY-AL CAST IN RTV-20 MOLD	0.209	0.018	4.740	0.006
EPOXY-AL CAST IN RTV-60 MOLD	0.179	-0.012	4.722	-0.012

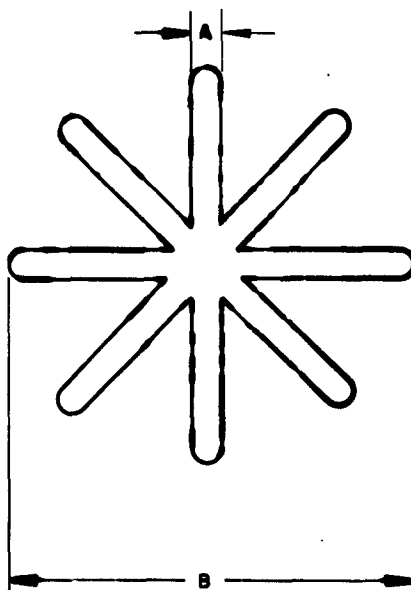


FIG. 4. Differences in Dimensions Between Plastic and Aluminum Mandrels for 12-Inch Diameter Spherical Motor.

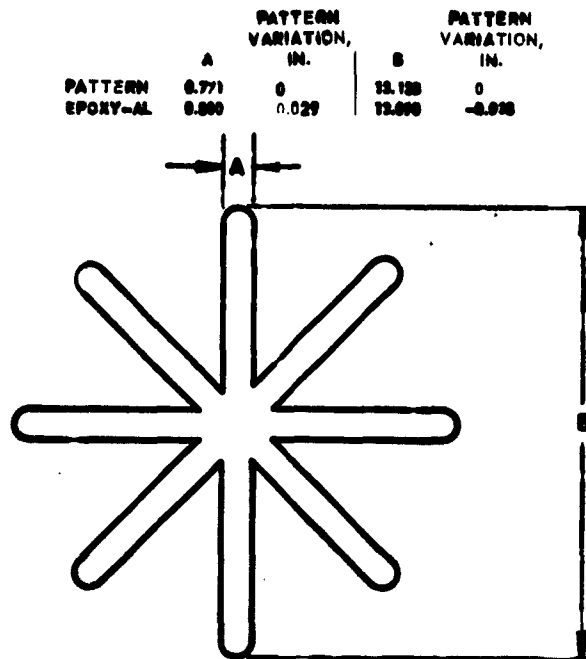


FIG. 5. Differences in Dimensions Between Plastic and Aluminum Mandrels for 24-Inch Diameter Motor.

Figure 6 shows the effect of varying the aluminum filler content on the thermal conductivity in plastic-mandrel formulations. Some types of propellant require curing by heating the inside of the mandrel as well as the outside of the motor, in order to lower the curing time. For these motors, special mandrels are used with heating tubes, cast into the epoxy-aluminum, acting as a hub for the fins. Therefore, formulations having high thermal conductivity are desirable. Two mandrels with internal heating pipes are shown in Fig. 7.

The surface roughness of the plastic mandrels is essentially the same as that of the pattern. Measurements of the roughness of various plastic mandrels were, on the average, from 14 to 30 microinches. The values read are probably accurate to ± 5 microinches. These data are presented in Table 3.

As described under Procedures, a thin coat of RTV-60 rubber is used as the release agent between the plastic mandrel and the propellant. This type of mold-release agent has several advantages over other types. The surface of the propellant is free of residue that might interfere with propellant ignition. The plastic mandrel may be used several times before recoating is necessary. Recoating is necessary periodically because of careless handling. As high as 40 releases from propellant have been obtained from a single coating.

Coating of the plastic mandrels with the RTV-60 rubber is made easier by the addition of SF-69 fluid. This allows the viscosity to be

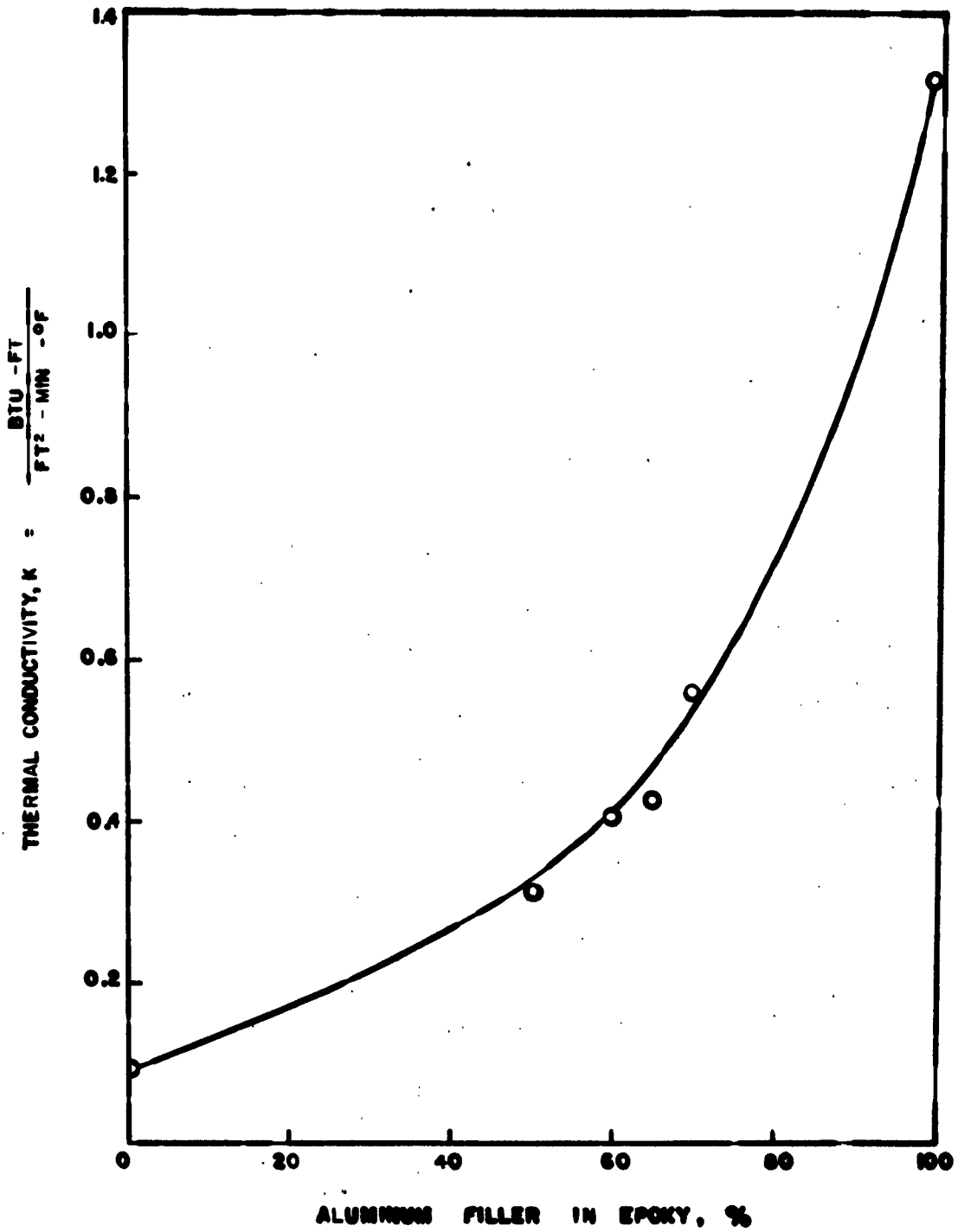


FIG. 6. Thermal Conductivity Versus Percentage of Aluminum Filler.



FIG. 7. Plastic Mandrels With Heating Pipes Cast in Place.

TABLE 3. SURFACE ROUGHNESS COMPARISON OF
PATTERN AND PLASTIC REPRODUCTION

Mandrel type	Finish	Pattern ^a	Plastic ^a
4 1/2-in. coned mandrel.....	1	20	18
4 1/2-in. coned mandrel.....	2	17	15
4 1/2-in. coned mandrel.....	3	17	14
4 1/2-in. coned mandrel.....	4	18	18
12-in. coned mandrel	1	25	25
12-in. coned mandrel	2	25	25
12-in. unconed mandrel	1	25	30
12-in. unconed mandrel	2	32	25
2 1/2-in. round mandrel .....	....	30	23

^aSurface finish in microinches. Measurements made on a Type Q Profilometer manufactured by Physicists Research Company, Ann Arbor, Mich. Tracer head type LA 4-33 was used.

varied over a wide range by varying the concentration of SF-69. An adequately low viscosity (5,000-10,000 cps) for coating the mandrels evenly can be obtained using 10-20% of SF-69.

It has been found that the addition of SF-69 affects the physical properties of the silicone rubber. Consequently, a dip process is being investigated that would eliminate the use of the SF-69 fluid. N-heptane is being used as the dispersion medium, with 5 to 10% RTV-60 or RTV-88 suspended in it. Low concentrations of catalyst will extend the pot life of the solution. Low percentages of RTV rubber in suspension are desirable, since forming very thin coatings will decrease costs and still be adequate for release purposes. Figure 8 is a series

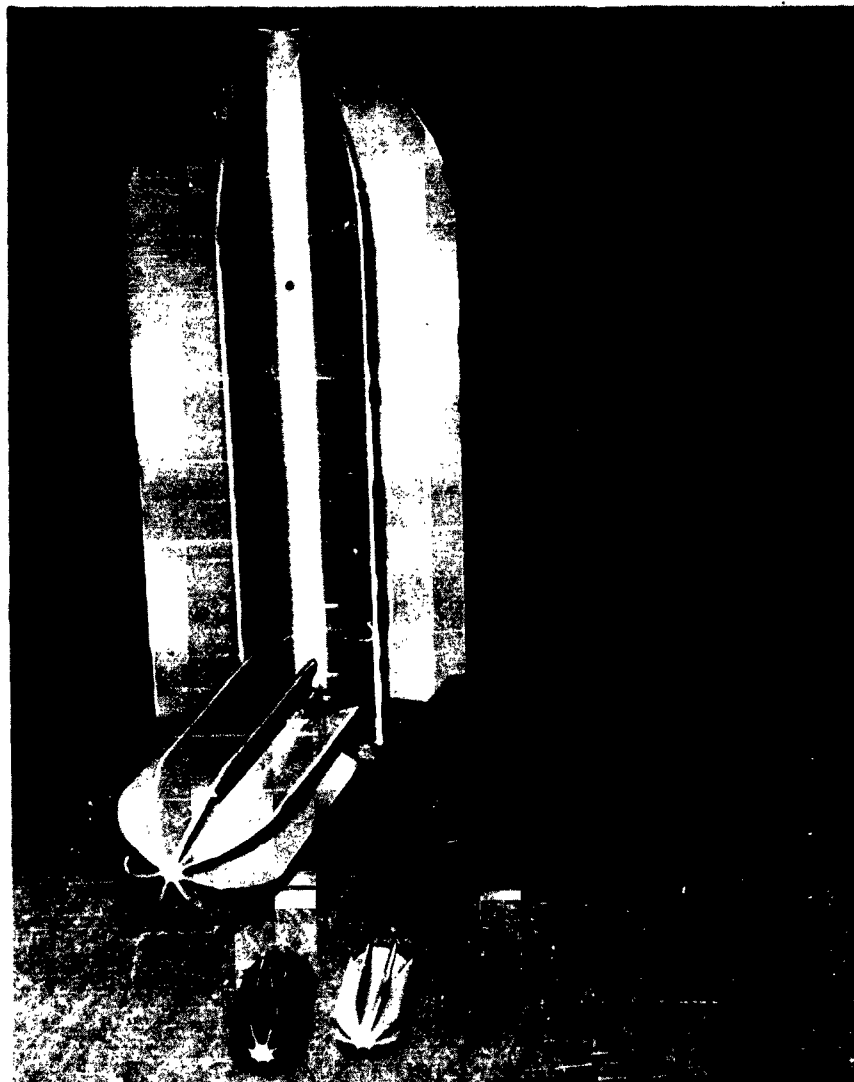


FIG. 8. Plastic Mandrels for 4.5-, 12-, and 24-Inch Spherical Rocket Motors.

of plastic mandrels that were produced for a family of spherical rocket motors.

Release properties of the RTV rubber, when applied to plastic mandrels, compare very well with the corresponding properties of mandrels coated with Teflon. In one case, a Teflon-coated mandrel released at 1.75 psi, and the RTV-coated mandrel required 1.95 psi. This difference is very small and insignificant since the reading accuracy is ± 0.25 psi. These pressure readings demonstrate that the RTV rubber does possess very good release properties.

An experiment was performed to develop the most satisfactory process for bonding the RTV rubber to the plastic mandrels to act as a release agent from propellant. Superior results were obtained by a combination of two primer systems. These data and the preparation of samples are presented in Table 4.

TABLE 4. AVERAGE STRENGTHS OF BOND FOR FOUR PRIMING SYSTEMS

Sample no.	Bond strength, psi ^a	Type of failure	Method of preparation
1	14	100% adhesive	Coated with XS-4004; dried for 2 hours; coated with RTV silicone rubber
2	23	95-100% adhesive	Primed with XS-4004; dried at 170°F for 15 minutes; reprimed with XS-4004; dried; RTV-60 cast on surface
3	18	100% adhesive	Same as sample number 1
4	129	0-15% adhesive in rubber	Primed with 81822; dried overnight; primed with XS-4004; dried; cast with RTV-60
5	133	30-60% adhesive in rubber	Primed with 81822; dried overnight; cast with RTV-60
6	148	0-5% adhesive in rubber	Same as sample number 4

^aEach strength is an average of five measurements.

Shown in Fig. 9 are two types of mandrels. Numbers 3 and 6 are the patterns. Number 3 is made of wood, and number 6 is steel. Numbers 2 and 5 are the plastic reproductions. Numbers 1 and 4 are the plastic reproductions after coating with RTV-60 rubber.

DISCUSSION

When comparing costs of plastic mandrels and aluminum mandrels, the means of producing the aluminum mandrel is important. The facilities at the U. S. Naval Ordnance Test Station dictate machining the mandrel from a solid billet. In such a case, the master mandrel is likely to cost from \$2,000 to \$3,000 for materials and labor. Subsequent machining of 20 identical mandrels does not lower the cost per

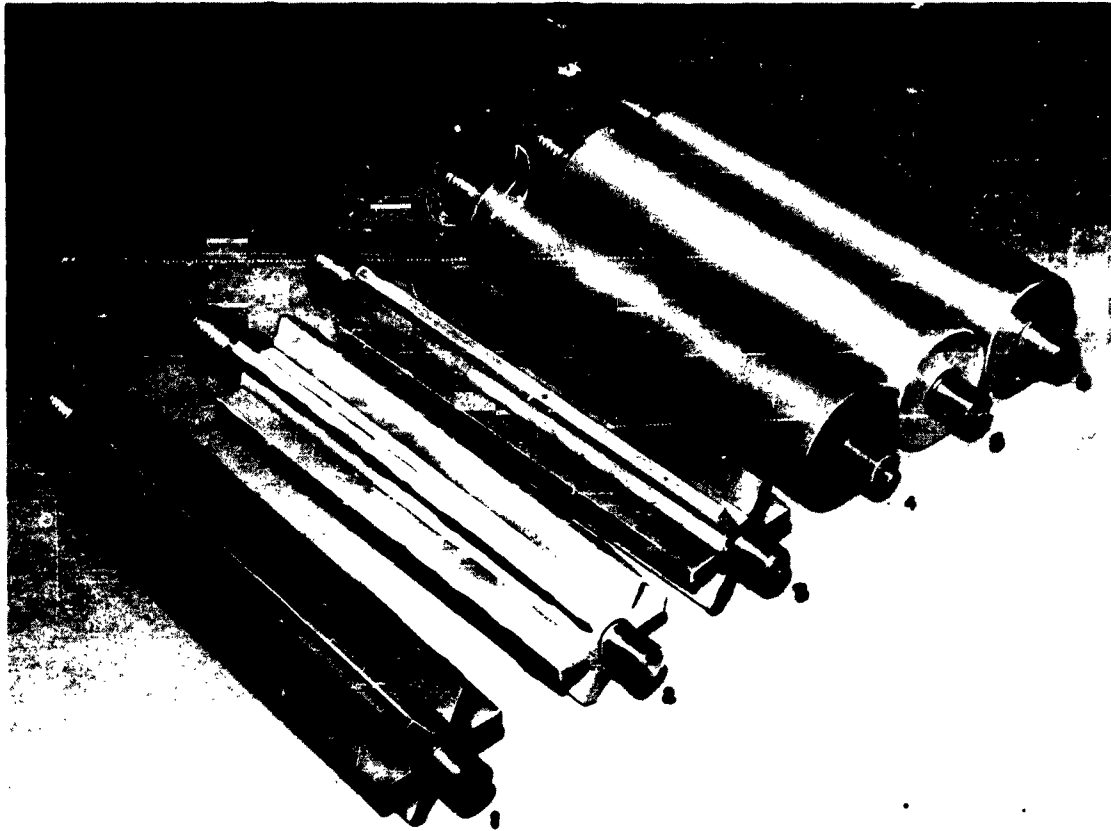


FIG. 9. Master Mandrels, Plastic Reproductions, and Plastic Reproductions Coated With Silicone Release Agent. Numbers 3 and 6 are the patterns, 2 and 5 are the plastic reproductions, and 1 and 4 are the plastic reproductions coated with RTV-60.

mandrel appreciably. In making plastic mandrels, the master mandrel also costs from \$2,000 to \$3,000. The plastic for a mandrel will cost approximately \$1.00 per pound. The RTV-60 rubber costs \$4.00 per pound. About 2 hours labor per mandrel is required on small plastic mandrels. For one aluminum mandrel, in particular, the pattern cost was \$3,000. The subsequent cost of 20 identical plastic mandrels was a total of \$508, or slightly over \$25 each. This cost included application of the RTV rubber release agent on each of the plastic reproductions.

If an aluminum mandrel can be extruded and chemically milled to give the desired tapered surface, this process is more attractive, economically, than machined mandrels. The cost of extruded and chemically milled mandrels is still likely to be about twice that of plastic mandrels.

Listed below are some of the advantages and disadvantages of plastic mandrels:

Advantages

1. The time for procuring mandrels is reduced.
2. The cost of producing mandrels is reduced.
3. The plastic mandrels are lighter and easier to handle than the metal ones.
4. Thermocouples may be cast in any desired area in the mandrel.
5. Heating elements can be encapsulated.
6. A single mold can produce 20 or more mandrels before patching is necessary.
7. A ruined plastic mandrel is inexpensive to replace since the central hub can be reused.
8. An inexpensive plastic mandrel can be modified to give an entirely new perforation design, without ruining a pattern or starting with a billet of metal.
9. No mold release agent is required on the RTV portion of the chase, therefore, excellent surface finishes can be reproduced.

Disadvantages

1. Small shrinkages create plastic mandrels slightly smaller than the pattern. (This can be adjusted by the thickness of the RTV mold-release agent applied or by making an oversize pattern.)
2. Epoxy-aluminum formulations have less strength than aluminum, resulting in a higher damage rate.
3. RTV release agent is more susceptible to scratching and peeling than a Teflon coating on aluminum.

FUTURE INVESTIGATIONS

Evaluations will be continued to improve the physical properties of plastic mandrels. One method to be studied is the use of polyamide-epoxy resin blends or other semirigid epoxies. Mixtures of a small portion of flake aluminum with atomized aluminum powder will be evaluated for their effect on thermal conductivity. Work in progress for coating plastic mandrels, by dipping, will be completed in the near future.

SUMMARY

Production of plastic mandrels by the process described is economically feasible. The use of RTV-60 rubber as a release agent on plastic mandrels is very satisfactory, since the cast propellant surface is residue-free after mandrel removal. The described release system is also re-usable many times before recoating is necessary.

Mandrel patterns may be fabricated of many materials. Aluminum, steel, epoxy-aluminum, and wood have been evaluated.

Plastic mandrels with good thermal conductivities may be produced by increasing the amount of atomized aluminum powder present in the plastic mandrels.

Good mandrel physical properties are obtained when mixtures of epoxies are used.

Reproduction of mandrel surface characteristics using RTV-60 silicone rubber molds is excellent. No significant difference in finish can be detected between a mandrel pattern and a plastic reproduction.

NEGATIVE NUMBERS OF ILLUSTRATIONS

**Fig. 1, L053326; Fig. 2, L053354; Fig. 3, L053349;
Fig. 4, None; Fig. 5, None; Fig. 6, None; Fig. 7,
L053362; Fig. 8, L053351; Fig. 9, L053364.**

ABSTRACT CARD

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A New Approach to Plastic-Mandrel Fabrication, by Ray A. Miller and Henry T. Sampson. China Lake, Calif., NOTS, June 1961. 16 pp. (NAVWEPS Report 7651, NOTS TP 2674), UNCLASSIFIED.

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Satisfactory mandrels for motors up to 24 inches in diameter and 84 inches in length can be made. Where several mandrels are required, producing plastic mandrels is economically feasible.

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