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CAST ACRYLIC PLASTIC DOME FOR UNDERSEA APPLICATIONS

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Jerry D. Stachiw

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13. ABSTRACT

An acrylic plastic hemispherical dome with a 78-inch outer diameter, 65.25-inch inner diameter and 7-inch-long skirt has been successfully cast, machined, and equipped with a metallic mounting flange. The mounting flange will allow mating of the cast plastic dome to a surface ship hull, where it will serve as an impact-resistant undersea observation chamber that will afford its occupants panoramic vision of subsurface hydrospace. Other potential applications for such cast domes are in deep submergence vehicles, continental shelf ocean bottom habitats, pressurized aquaria, and hyperbaric chambers. This dome is applicable to depths in the 0- to 2,500-foot range providing that the right method is used for attaching the dome to the vehicle or habitat. The mechanical properties of the massive dome casting have been found to be significantly less than the typical properties of flat plates cast solely from acrylic monomer.

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1-A

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by
Jerry D. Stachiw
Ocean Technology Department

January 1974

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NUC

NAVAL UNDERSEA CENTER, SAN DIEGO, CA. 92132

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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Commander

Wm. B. McLEAN, Ph.D.
Technical Director

ADMINISTRATIVE STATEMENT

This report summarizes work performed between July 1972 and June 1973 to investigate transparent structural materials for undersea application. The work was supported by the Director of Naval Laboratories through the Independent Exploratory Development Program.

ACKNOWLEDGEMENT

The author is indebted to Mr. A. E. Nichols, Jr. of Cadillac Plastic and Chemical Company for his technical contribution to the successful casting of the acrylic plastic dome.

Released by
H. R. TALKINGTON, Head
Ocean Technology Department

SUMMARY

PROBLEM

Large, acrylic plastic domes for deep submergence applications have been built primarily by bonding small, thermoformed structural modules. The large amount of hand labor required by this approach makes such domes relatively expensive.

RESULTS

A casting technique utilizing a glass fiber-reinforced plastic mold system composed of male and female molds filled with monomer/polymer casting syrup has been shown to be capable of producing massive domes of at least 78-inch diameter and 6.375-inch thickness with significant saving in labor over domes built by bonding small structural modules. The dimensional deviations of massive domes cast by this technique are higher than those of machined massive modular domes but less than those of thin domes free-formed by compressed air.

RECOMMENDATIONS

The casting of massive acrylic plastic domes in glass fiber-reinforced plastic molds should be considered as an economically attractive technique for production of massive domes for deep submergence application.

CONTENTS

INTRODUCTION

Many ocean engineering systems require transparent structural components that serve as windows. Since the size of the window directly influences the field of view that the window provides, a premium is placed on size. However, large sizes require that windows be quite thick.

Thick, plane, acrylic plastic windows can be readily manufactured either by laminating many thin sheets or by casting massive blocks. In either case the technology is well developed and plane, acrylic plastic windows of almost any thickness and size can be obtained from industrial suppliers on a fixed-price basis. Still, plane windows are not as much in demand as are spherical shell windows, whose shape makes them structurally superior (references 1-10).

Unfortunately, the technology for the fabrication of spherical shell windows is not so advanced as is that for plane windows. Thin windows can be readily fabricated by blowing with compressed air, with or without a mold, but the resulting hemispheres are of varying thickness and must be limited in their operation to shallow depths. Thick windows have been fabricated only (1) by laminating many thin, blown shells; (2) by hogging-out massive castings; or (3) by assembling and bonding many small structural segments. Of these three approaches, the laminating produces shells of varying thickness, while the hogging-out is prohibitively expensive. Only the bonding of small, identical segment assemblies has produced thick, spherical shell windows of uniform thickness at a tolerable price. It was this technique which was used to fabricate spherical hulls for the NEMO, MAKAKAI, and JOHNSON SEA LINK deep submergence vehicles. Bonding left a lot to be desired in terms of cost, because it entailed an inordinate amount of hand labor. Obviously, another technique was needed that would require significantly less hand labor while producing thick, spherical windows with acceptable dimensional tolerances.

A fabrication technique which seemed promising was the casting of monolithic hemispheres. It was thought that if problems of excessive shrinkage, cracking and generation of bubbles during the polymerization process could be surmounted without excessive investment in tooling, this process would permit the production of inexpensive, spherical, acrylic plastic windows of large size.

Realizing the potential savings if an inexpensive casting technique could be developed, the Naval Undersea Center initiated studies of two casting techniques. The first would minimize the cost of tooling in exchange for allowing (1) large dimensional tolerances in the sphericity, diameter and thickness of the casting and (2) a large amount of hand labor for polishing of the cast surfaces. The second would (1) minimize the amount of hand labor for polishing and (2) keep the thickness, sphericity and radius within tight dimensional tolerances, but would require expensive tooling. This paper describes the first study.

DISCUSSION

DESIGN OF DOME

The objective of the casting technique study was the fabrication of an acrylic plastic hemisphere with a nominal 78-inch outer diameter, 65.25-inch inner diameter and 7-inch cylindrical skirt. This dome was dimensioned to serve as an undersea observation chamber for the small waterplane area hull vehicle SSP KAIMALINO. Since the observation chamber was to be mounted only approximately 12 feet underwater, the hydrostatic pressure was not of sufficient magnitude to control the structural design of the dome.

Instead, the thickness of the dome was chosen on the basis of the dynamic impact to which the hull could be subjected when accidentally striking a water-logged floating log. The 6.375-inch thickness chosen for the dome represented a good compromise as it gave the dome a reasonable impact resistance (roughly equivalent to that of 0.375-inch mild steel) while at the same time keeping its weight and cost at an acceptable level.

An additional benefit of such a thick wall was that the dome could also serve as a panoramic window for submersibles and ocean bottom habitats operating to a depth of 1,000 feet. In this manner, once the tooling was fabricated for casting of the dome, the output of the tooling would not be limited to impact-resistant transparent bows for surface ships, but also would provide relatively inexpensive observation cupolas for submersibles and undersea habitats.

ATTACHMENT FOR THE DOME

Besides operational parameters like hydrostatic pressure and dynamic impact, the method of attaching the 3,000-pound acrylic casting to the metallic hull of the SSP KAIMALINO had to be considered. The pitching of the hull in rough water, depending on its amplitude and frequency, could subject the acrylic casting to gravitational forces in excess of 10,000 pounds. Forces of such magnitude and the presence of seawater eliminated adhesives from the consideration for attachments.

Several mechanical attachment systems were considered before settling on the chosen design. Those that were considered, but ultimately rejected, were attachments that required either straps or retaining bars pressing against the convex surface of the dome and thus restricting the panoramic view from inside the dome. The design finally chosen relied on mechanical fastening like those rejected, but because of its layout did not obstruct in any manner the view from inside the dome.

The basic features of the attachment chosen for fabrication (figures 1 and 2)* are these:

1. A metallic, U-shaped flange restrains the dome against vertical static and dynamic forces and provides the foundation to which the metallic hull of the vehicle and the split ring of the dome attachment are fastened. The dome fits into the flange rather loosely

The figures and table 1 are grouped at the end of the text.

(approximately 0.125-inch clearance between the surfaces of the dome and interior of the flange) to allow room for (a) thermal expansion and contraction of the dome under typical conditions and (b) contraction of the dome under hydrostatic loading encountered at 12 feet.

2. A metallic split-ring restrains the dome against static and dynamic horizontal forces. The split ring fits rather snugly against the inner surface of the flange but rather loosely (approximately 0.125-inch clearance) against the acrylic surface. Because of this arrangement, the split ring can be fastened quite securely with bolts to the flange while still allowing for limited radial and axial displacement of the dome due to thermal expansion and hydrostatic loading.

3. An elastomeric filler (silicone rubber) between the acrylic dome and the metallic components of the attachment serves both as a seal against water and as a compliant cushion preventing high stress concentrations at point contacts.

4. A cylindrical skirt on the dome mates with the metallic components of the attachment. To fit properly with the mating metallic parts of the attachment all surfaces of the skirt have been machined to close tolerances. This was necessary as the casting process chosen would not produce surfaces on the skirt to the desired close tolerances.

CASTING TECHNIQUE

The casting technique chosen* required that (1) a mix of acrylic monomer resin and polymer granules be placed into (2) glass-fiber reinforced epoxy molds that were subsequently subjected to (3) elevated temperature and pressure inside an autoclave. Since acrylic spherical castings of such magnitude had never been cast before and a very distinct possibility existed that the first attempt would be an expensive failure, a scale model of 24 inches outside diameter and 2 inches wall thickness was cast first. When this casting was successful it was decided to proceed with the full scale 78-inch-diameter casting.

The distinctive feature of the casting arrangement chosen was the use of a sprue located at the apex of the dome to concentrate all gas bubbles in a part of the casting that would be subsequently cut off without decreasing the size of the finished dome. An alternative approach to removal of the gas bubbles from the casting would be to place the molds upright and to pour the casting mix between the male and female molds. In this arrangement the bubbles would rise and concentrate in the base of the cylindrical skirt. After polymerization several inches of the skirt base containing the bubbles would be machined off, leaving behind a bubble-free casting.

The basic reason for not choosing the alternative casting arrangement was the 7-inch length of the skirt required to attach the finished dome to the vehicle hull. If bubbles were to be concentrated in the base of the skirt, an additional 3 to 5 inches of skirt length would have to be added to the rough casting. The resulting 10- to 12-inch cylindrical skirt probably would make the removal of the male mold very difficult as the casting mix shrinks approximately 8 to 10 percent upon polymerization and would grip the cylindrical portion of the mold quite securely.

*The casting process is a proprietary development of Cadillac Plastics and Chemical Company of Kalamazoo, Michigan.

MACHINING OF DOME

The successfully cast dome (figures 3 and 4) contained gas bubbles only in the upper 5 inches of the sprue; the dome casting proper was virtually bubble-free. The first operation was to machine the sprue flat so that it would serve subsequently as the base for the dome during machining of the skirt surfaces (figure 5) in a vertical mill. Next, the sprue was completely removed and the exterior surface was sanded (figure 6). Material test samples were also cut from the sprue and used to test the mechanical properties of the casting (figure 7, table 1). Finally, the interior surface of the dome was sanded and all surfaces were polished (figure 8). The completed dome was then carefully inspected (figure 9) and its dimensions recorded.

FABRICATION OF ATTACHMENT

The U-shaped flange was fabricated by rolling and welding strips of mild steel. The rough U-channel structure was machined to final shape on the same vertical mill (figure 10) that was used for machining of the cast dome. Bolt holes for fastening of the flange to the hull and for attachment of the split ring to the flange were drilled with a portable drill held in a magnetic clamp fixture.

The split ring was fabricated by rolling, welding and rough grinding of mild steel strip. The ring (figure 11) was cut with a hacksaw in one place just prior to mating of the attachment components to the dome.

MATING OF ATTACHMENT TO THE DOME

The first step in mating of the attachment to the dome consisted of plugging the holes in the U-shaped flange so that the liquid elastomer would not leak out prior to its polymerization (figure 12). The holes in the base were covered with 0.25-inch-thick neoprene patches that not only covered the bolt holes but also served as spacers between the dome and the bottom of the U-shaped flange. Without the presence of the neoprene spacers the heavy dome would displace the liquid elastomer completely and the base of the skirt would bottom against the steel surface.

The second step in the mating procedure was to compress and insert the split ring into the machined groove in the casting skirt (figure 13). Now the dome was ready for mating with the U-shaped flange.

The third step was filling of the U-shaped flange with the elastomeric compound (Dow Corning Two-Part Room Temperature Polymerizing 3110RTV Compound) and immediately lowering the dome into the flange until the skirt bottomed on the neoprene spacers and the surplus elastomer was squeezed out (figure 14).

The fourth and final step of the mating procedure after the elastomer solidified was to draw up the split ring against the U-shaped flange with the help of radially oriented bolts. Removal of the extruded elastomer and external dome lifting clamp completed the mating of the attachment to the dome.

OBSERVATIONS

The mechanical properties of the acrylic plastic casting described in this paper differ significantly from those of acrylic sheets and plates (Plexiglas G, Acrylite, Swedlow ...0) cast solely from monomer resin (table 1). A general statement can be made that the cast acrylic in the dome has lower tensile, flexural and compressive strength; lower modulus of elasticity; and higher creep than typical cast acrylic sheets and plates. This is typical of acrylic plastic castings formed by polymerization of a mixture containing both the monomer resin and polymer granules. The lower mechanical properties of such castings must be taken into account in the calculation of allowable working stresses for structures fabricated from them. This is particularly true when the design of cast spherical domes or sectors is based on empirical data generated previously by the destructive testing of scale models of spherical windows machined from thick Plexiglas plates that have higher mechanical properties than the full scale cast spherical dome.

Dimensions of the rough dome casting deviated noticeably from specified nominal dimensions (figure 9). The deviations were not serious enough to hamper the dome's use as a transparent bow on a surface ship but they would place serious restrictions on its operational depth as a potential panoramic window for submersibles. The most serious deviation from specified nominal dimensions occurred near the apex, where there was a visually noticeable thinning out of the dome shell around the circumference of the sprue base. This was caused by the difference in shrinkage between the 6.375-inch-thick dome and the 20-inch-diameter sprue during the polymerization process. If the outer surface of the dome had been machined to eliminate any optical distortion in the dome by smoothing out the shrinkage valley, the thickness at the apex of the dome would have decreased from the specified 6.375 inches to 5.0 inches.

This observation suggests that to produce domes with only minor thickness variations using this technique it is necessary to either (1) modify the existing molds at the intersection between the sprue pipe and the female mold so that when the shrinkage takes place the thickness of the shell at the base of the sprue pipe does not decrease below the specified nominal thickness, or (2) remove the sprue pipe, patch the sprue pipe opening, invert the molds, increase their skirt length and pour the casting mix into the annular space between male and female molds. Of these two modifications to the existing molds, the former is the more economical and, besides, attempting to remove a dome casting with increased skirt length from an inverted mold might meet with failure.

Quality of the casting was very high except for some minor imperfections on the exterior surfaces. These imperfections were caused by putting too thick a layer of mold-release agent on the interior surfaces of the glass fiber-reinforced molds; this formed ridges and drops in some places on the mold which were subsequently faithfully reproduced in the acrylic casting. In general it appears that the rough surface finish of the molds, coupled with uneven application of the mold release agent, required an extensive amount of hand labor for sanding and polishing of surfaces on the dome.

FINDINGS

1. Molds made of plastic reinforced with glass fibers present an economical approach to tooling for the production of large, spherical shell acrylic castings providing that the permissible tolerances on thickness, diameter and sphericity are at least ±0.250 inches. To achieve tighter dimensional tolerances than ±0.250 inches the dome casting must be made slightly oversize and subsequently machined down to the desired size.

2. The quality and mechanical properties of the acrylic plastic dome cast in glass-reinforced plastic molds by Cadillac Plastic is acceptable for hydrospace applications providing that the lower mechanical properties of the casting as compared to properties of commercially available cast acrylic plate are taken into account.

3. The design developed for the attachment of a hemispherical acrylic plastic dome to the metallic hull of a ship has been found to be economical to fabricate and easy to assemble with the dome.

CONCLUSIONS

It is feasible to cast very large acrylic plastic domes that do not require any subsequent machining on the viewing surfaces at a reasonable investment in tooling and hand labor for polishing providing that one can accept deviations from nominal dimensions which exceed those customarily associated with machined domes but are significantly less than those associated with vacuum- or pressure-formed domes from flat acrylic sheets.

RECOMMENDATIONS

It is recommended that the casting technique described in this report be utilized for those hydrospace applications where (1) only one or two very large, thick acrylic plastic domes of the same size are required and (2) the hydrostatic loading of the dome will be of such magnitude that the dimensional tolerances of ±0.250 inch on the thickness, diameter and sphericity can be readily accepted. If the casting technique is used for the applications enumerated above it will provide the hydrospace engineer with very large domes at a rock bottom price.

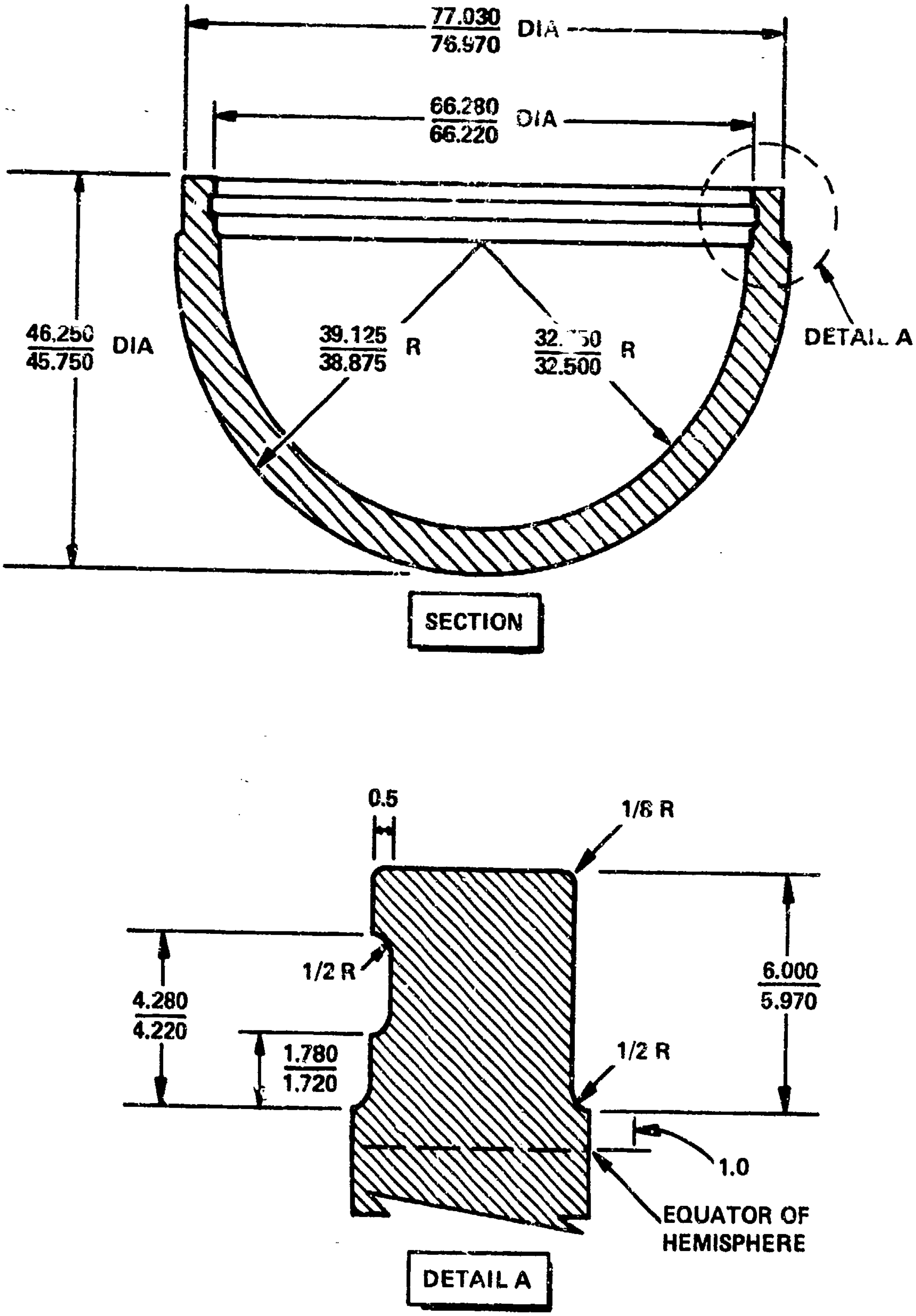

Figure 1. Dimensions specified for the finished acrylic plastic dome casting.

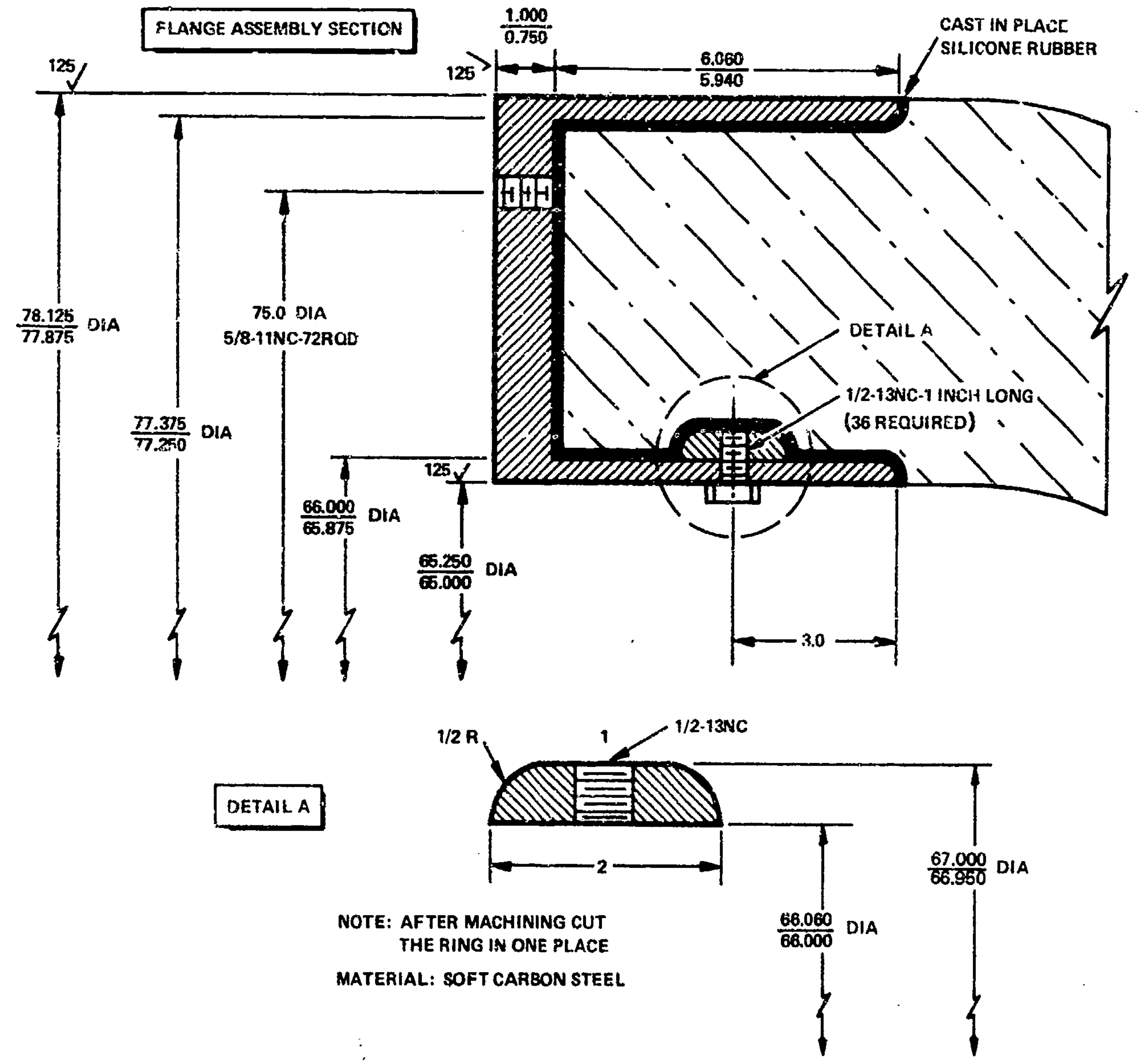

Figure 2. Attachment for fastening the acrylic plastic dome to vehicle hull.

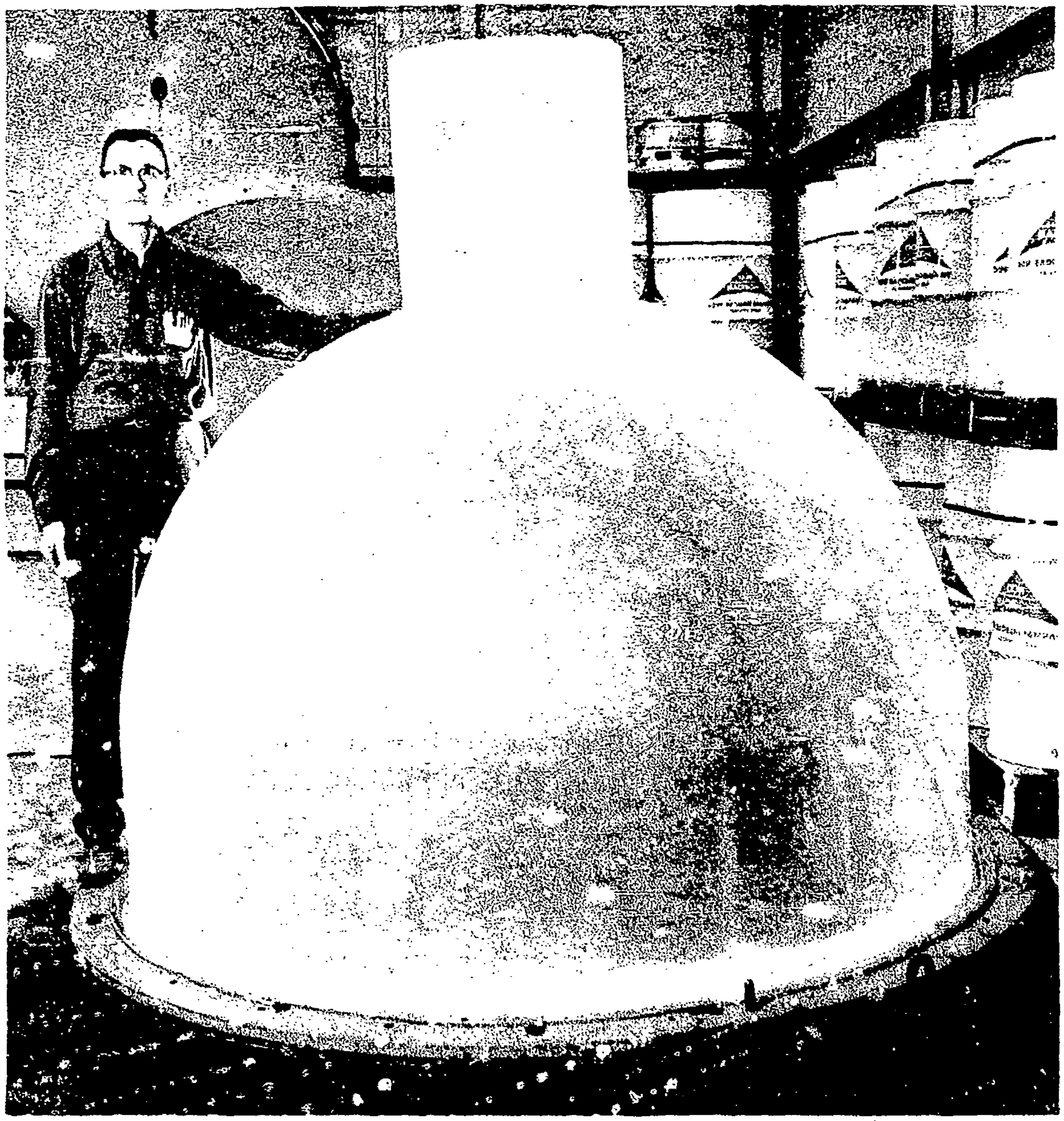

Figure 3. Rough casting of the dome after removal from the molds.
Note the big sprue at the apex of the dome.

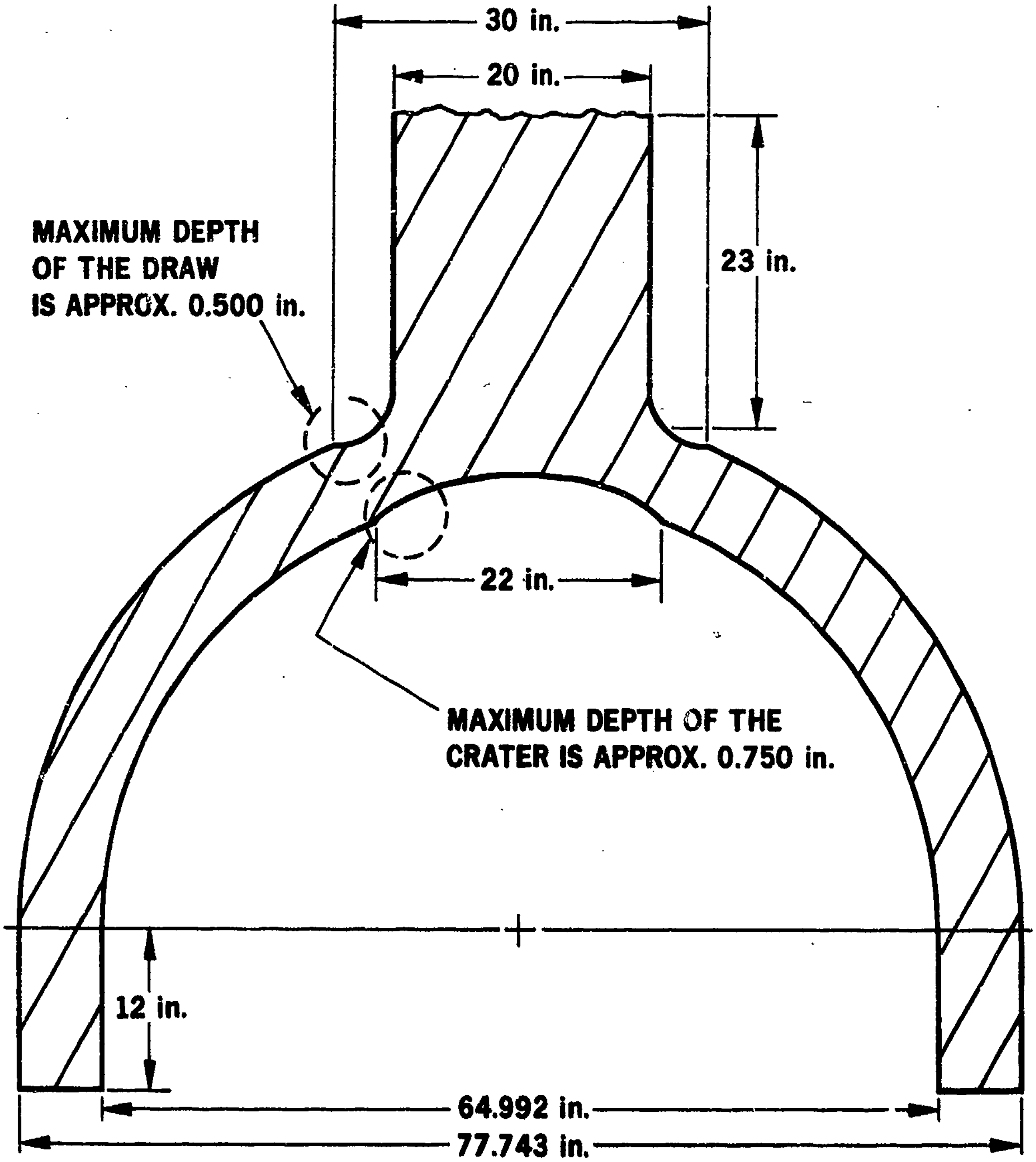

Figure 4. Dimensions of the dome casting prior to machining.

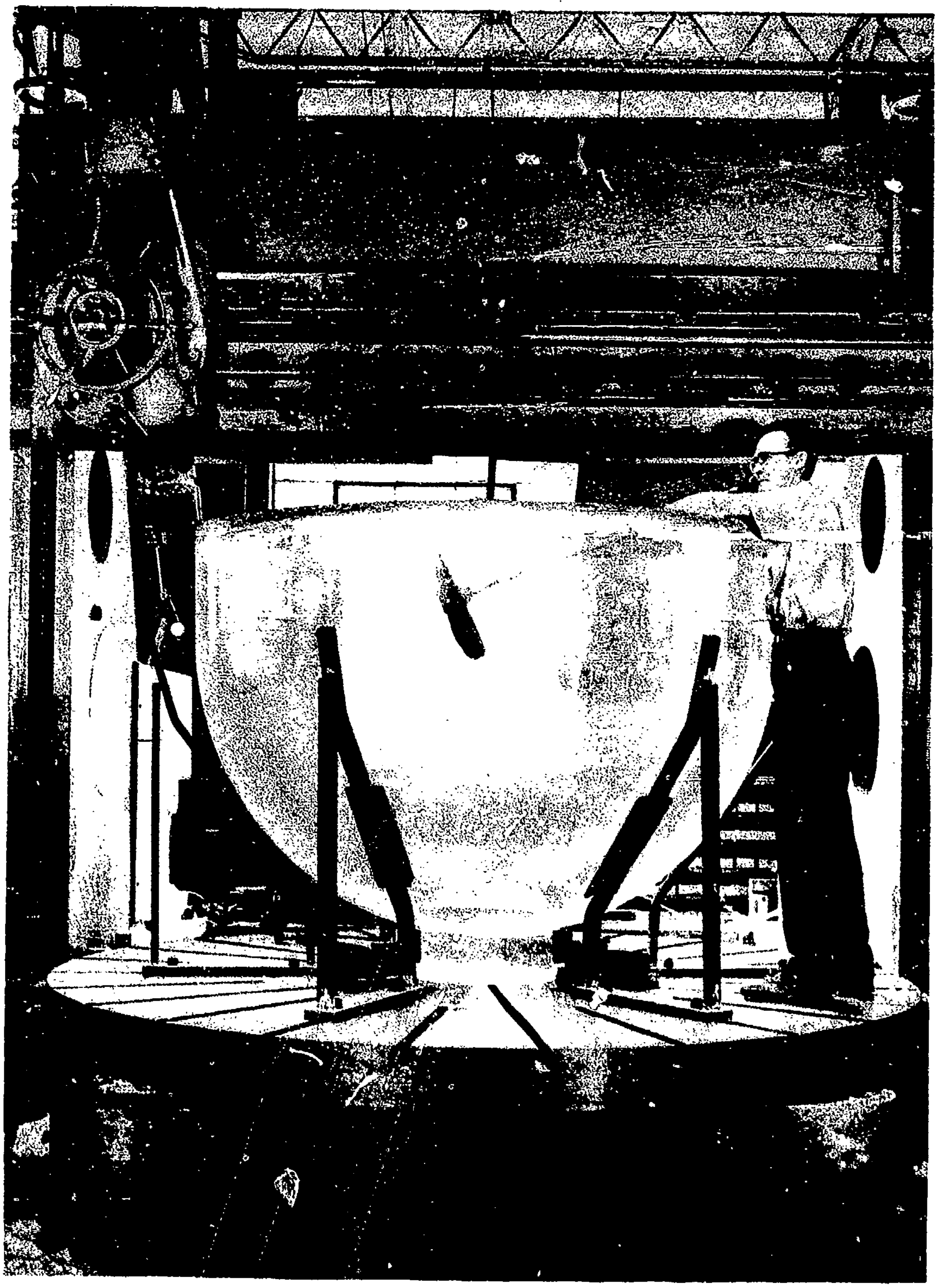

Figure 5. Machining the skirt on the dome.

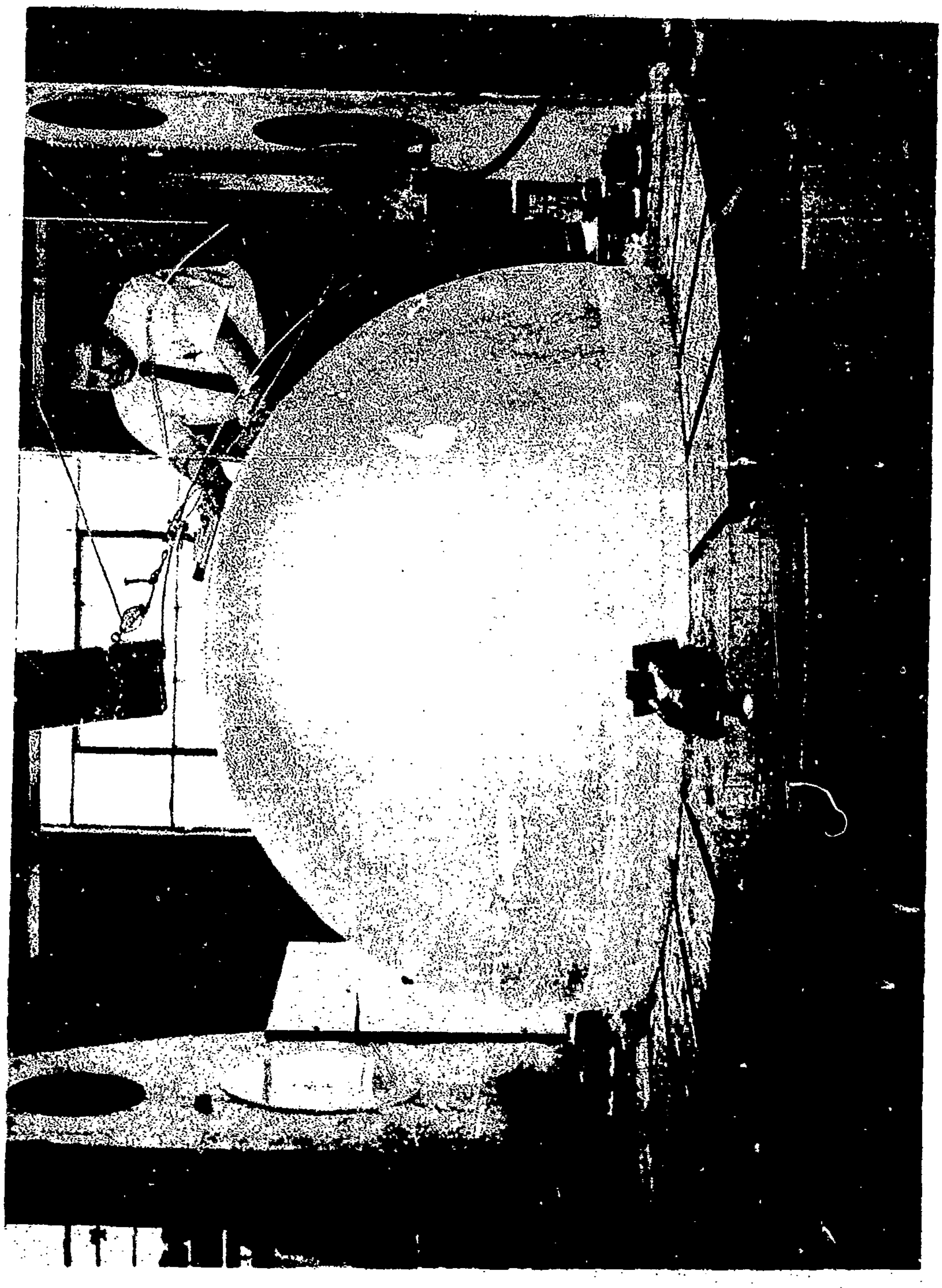

Figure 6. Machining off the sprue on the dome.

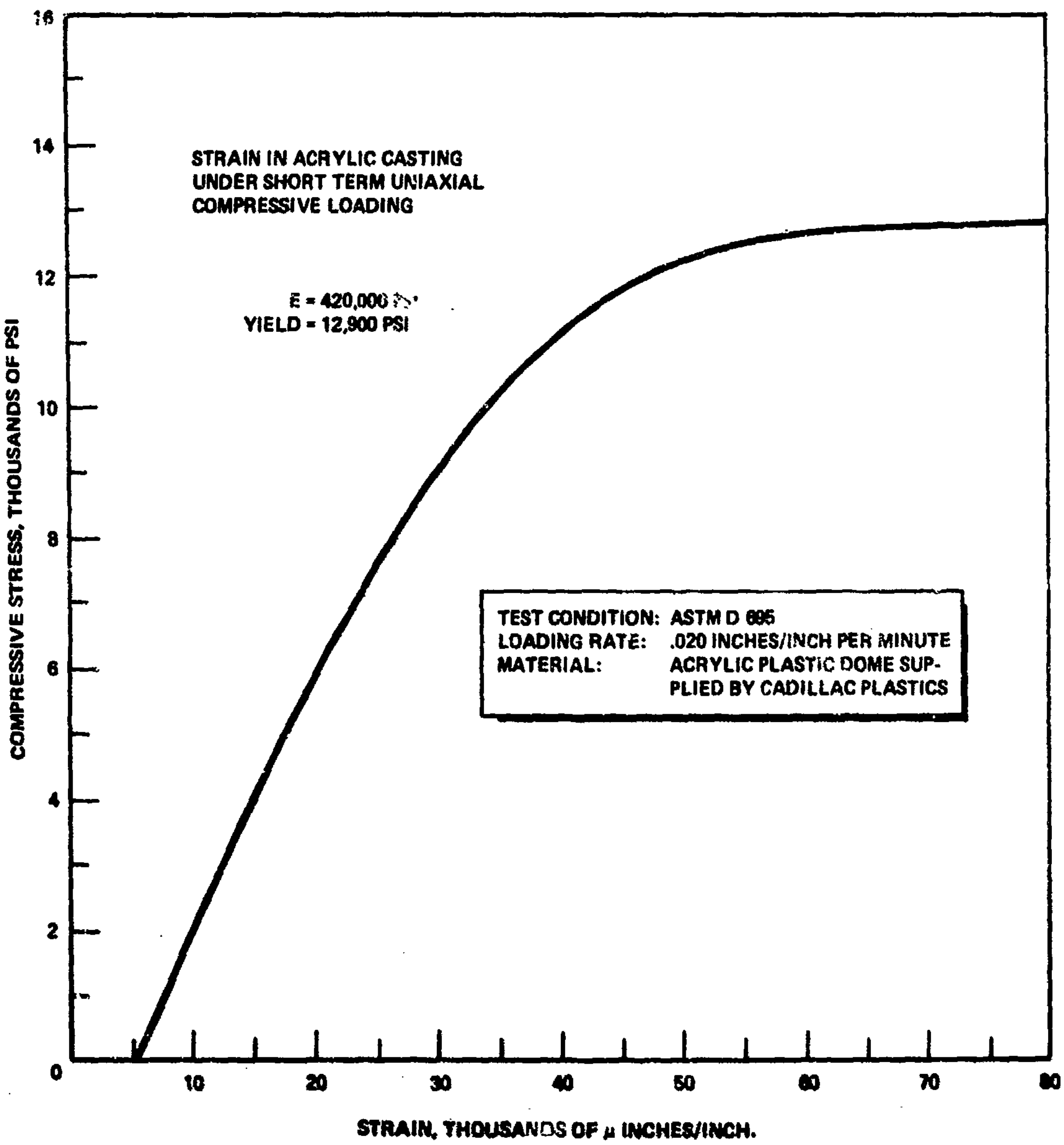

Figure 7. The stress-strain relationship of a material test specimen under uniaxial compressive loading; the test specimen was cut from the sprue adjacent to the dome.

Figure 8. Polishing of the dome with power-driven buffing wheel.

Figure 9. The finished acrylic plastic dome is [illegible] by Dr. J. D. Stachiw, acrylic plastic structure expert at NUC, and Mr. A. Nichols, casting sp[illegible] at Cadillac Plastic.

Figure 10. Machining of the U-shaped flange.

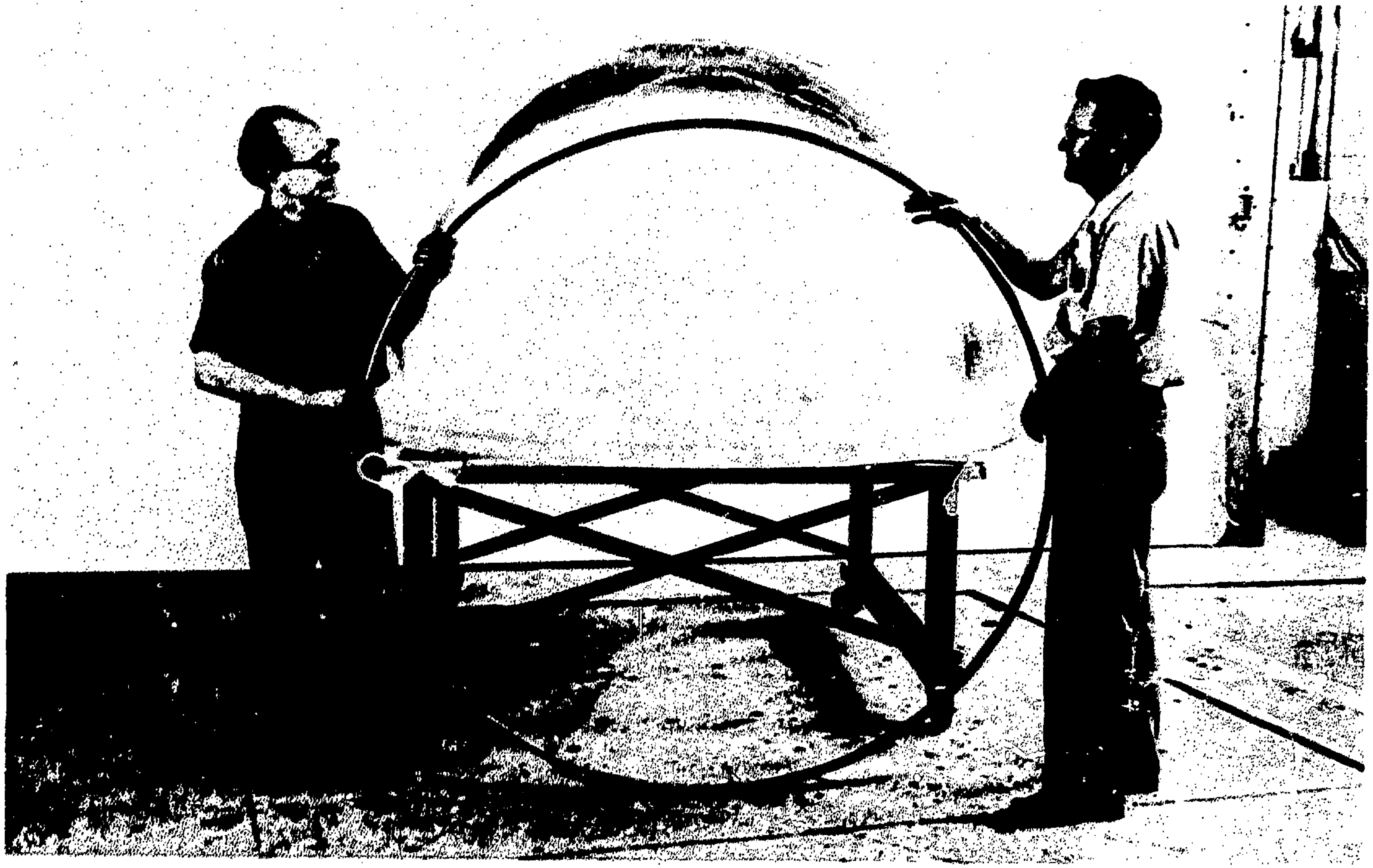

Figure 11 Finished split ring that locks the dome's skirt in the U-shaped flange.

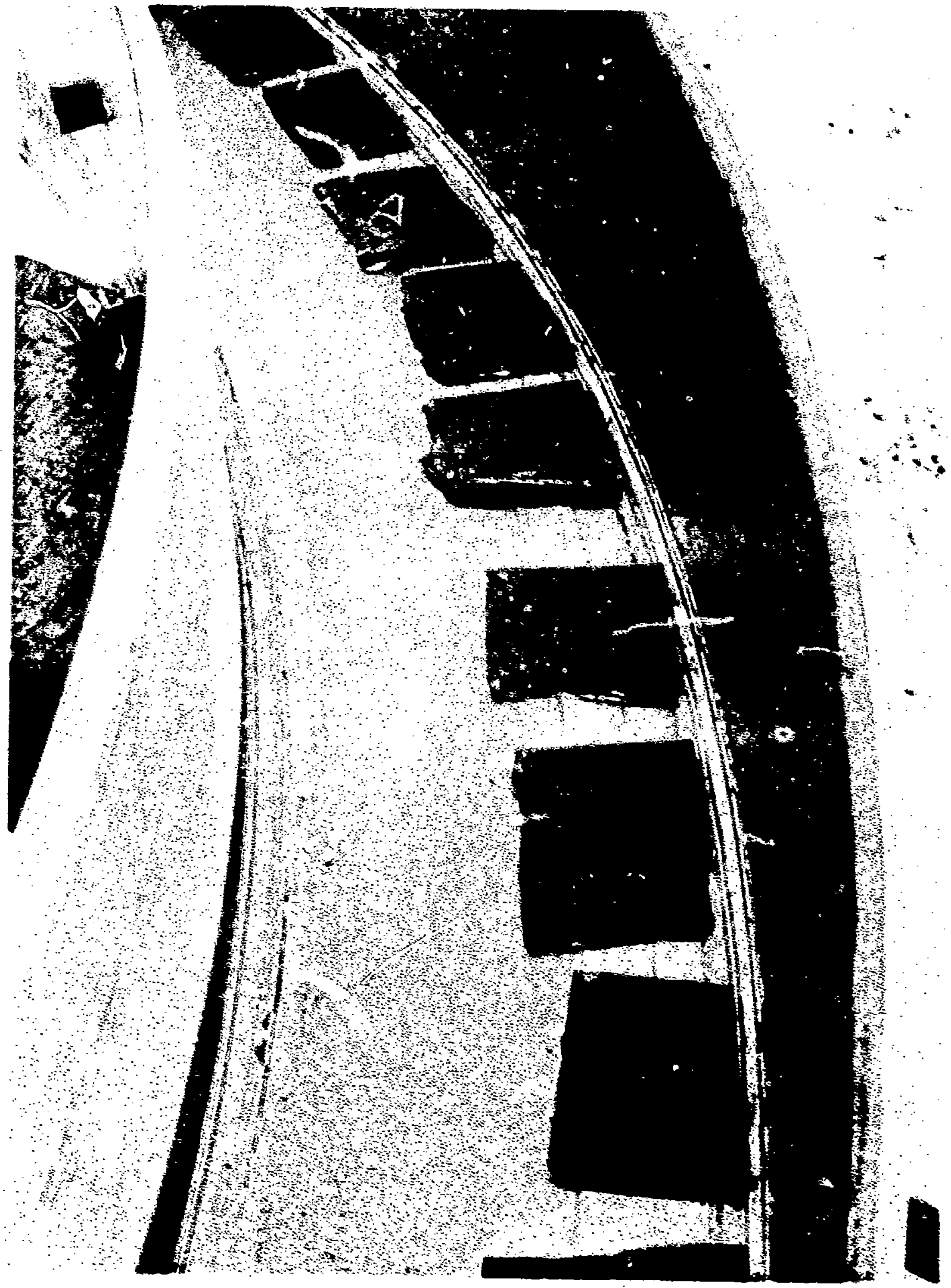

Figure 12. U-shaped flange just prior to pouring of the elastomeric sealant. Note the stoppers plugging the radial bolt holes in the left side of the flange and the neoprene bearing pads covering the axial bolt holes in its bottom.

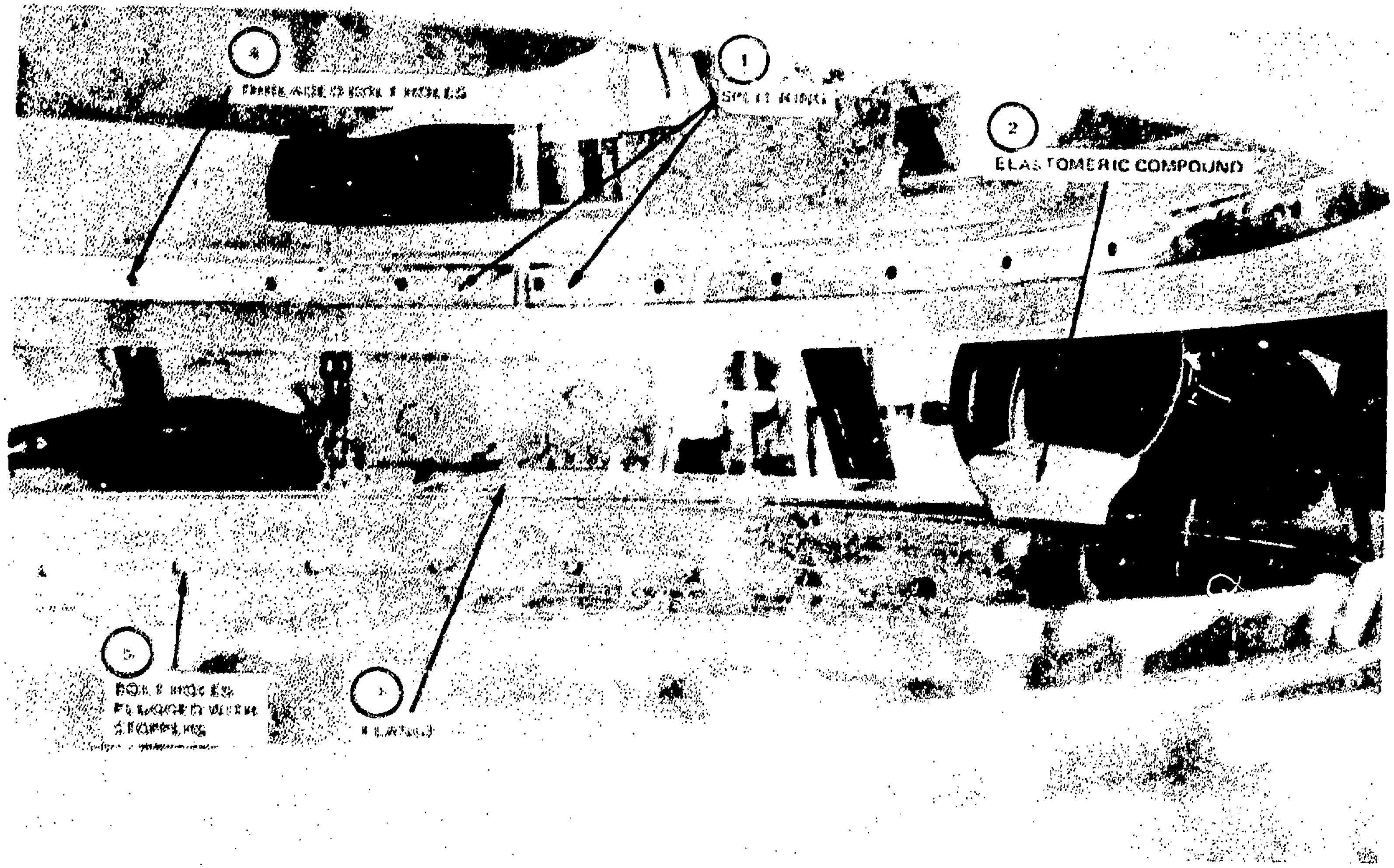

Figure 11. Mating the dome to the U-shaped flange. The split ring(1) is already resting in the groove machined for it in the dome skirt and the elastomeric compound(2) is being poured into the U-shaped flange(3) prior to insertion of the skirt into the flange. Note the threaded bolt holes(4) in the split ring and the stoppered bolt holes(5) in the flange.

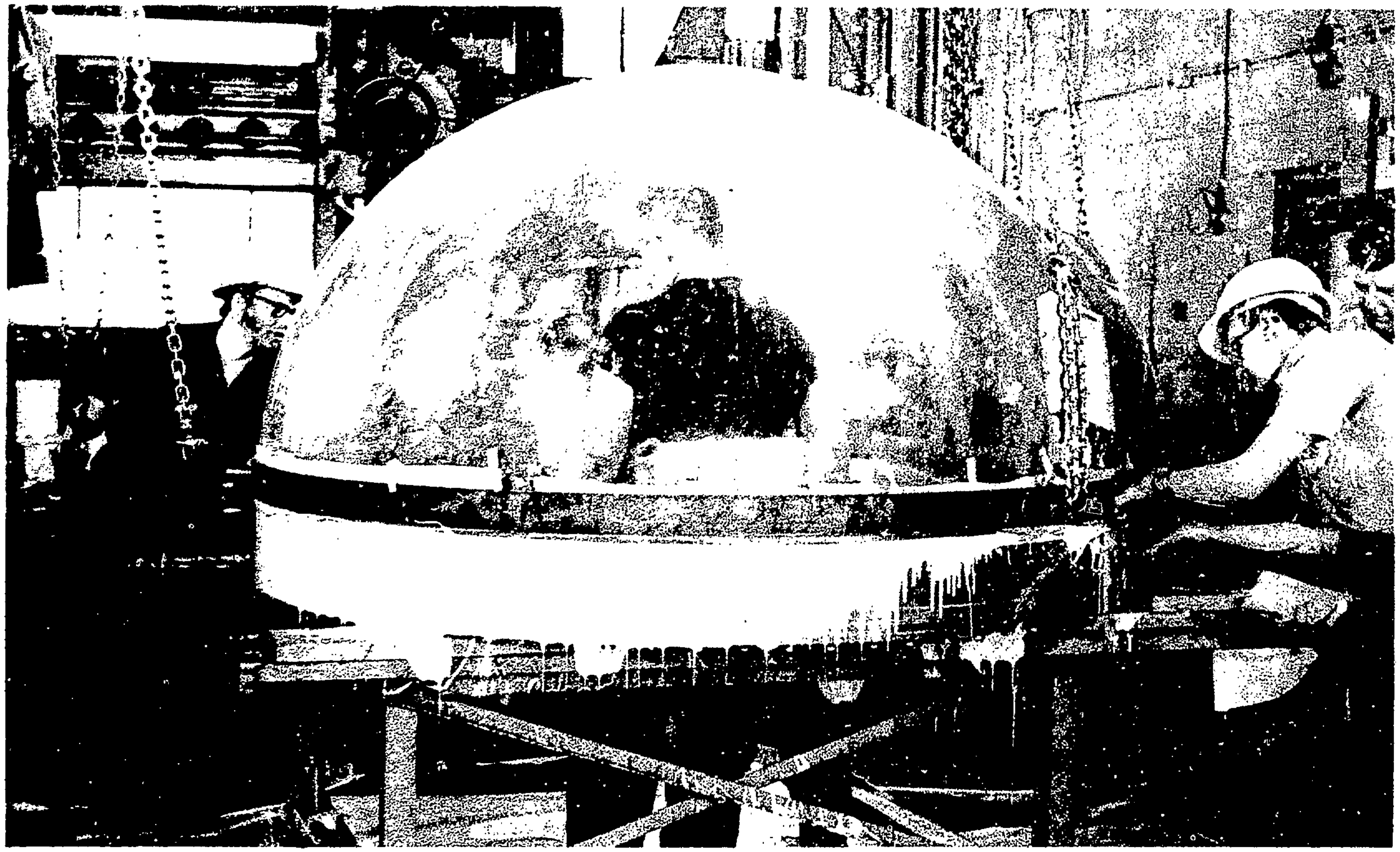

Figure 14. Dome after the mating with the flange has been completed. The displaced elastomeric compound signifies that all spaces between the dome skirt and the flange have been filled. Note the external lifting clamp surrounding the dome's base and the chains by which the dome is lowered into the flange.

Table 1. Mechanical Properties of Material.

A. Acrylic Plastic Casting.

Type of test	[a]Cast acrylic plastic sheets and plates	[b]Massive hemisphere casting
Compressive yield Compressive modulus ASTM-D-695	15,000 psi 420,000 psi	12,900 psi 415,000 psi
Tensile strength Tensile modulus Tensile elongation ASTM-D-638	9,000 psi 400,000 psi 2 percent	8,100 psi 410,000 psi 4.8 percent
Flexural strength Flexural modulus ASTM-D-790	14,000 psi 420,000 psi	not available not available
Shear strengths ASTM-D-732	8,000 psi	not available
Deformation under load (4000 psi at 122°F for 24 hours) ASTM-D-621	1 percent maximum	0.96 percent

NOTES:

[a]Minimum properties specified for acrylic plastic viewports fabricated from sheets or plates – MIL-C-24449.

[b]Actual values obtained by testing of coupons cut from the massive hemisphere casting.

Table 1. (Continued)

B. Silicone elastomeric compound[c] (Dow Corning 3110 RTV)	
Color[2]	White
Deep section cure, 1-in. depth in metal can	Yes
Recommended Primer	1201
ASTM D 445. Viscosity at 25°C (77°F), poises	125
ASTM D 792. Specific gravity at 25°C (77°F)	1.17
MIL-S-23586. Corrosion resistance	Good/Pass
ASTM D 412. Tensile strength, psi	350
ASTM D 412. Elongation, percent	200
ASTM D 676. Durometer hardness, Shore A	45
Linear shrinkage, percent, 3 days at 25°C (77°F)	0.4
Radiation resistance, cobalt 60 source, 25°C (77°F), megarads	100
ASTM D 570. Water absorption, percent, 7 days at 25°C (77°F)	0.4
Temperature range, degrees	-65 to 200°C (-85 to 392°F)
Thermal conductivity, Cenco-Fitch, 25–100°C (77–212°F, gm cal/cm^2-sec-(°C/cm)	5.0×10^{-4}
MIL-1-16923C. Thermal shock, 10 cycles	Pass
Weight loss 96 hrs/200°C (392°F), percent	6
Volume expansion 25–150°C (77–302°F) cc/cc/°C	7.5×10^{-4}
Specific heat, cal/gm/°C	0.35
ASTM D 746. Brittle point, degrees	-100°C (-143°F)
Fire resistance	Self-extinguishing

[c]Typical values supplied by Dow-Corning for 3110 RTV.

APPENDIX: DESIGN HINTS

For those engineers interested in utilizing the casting technique for acrylic plastic domes or the design developed for the attachment of these domes to vehicle hulls, some brief discussion of their limitations is in order.

CAST MATERIAL

Because the mechanical properties of cast massive acrylic plastic domes differ significantly from those of domes formed and subsequently machined from thick, commercially available plastic plates (for example, Plexiglas G, Acrylite or Swedlow 310), lower stress levels must be utilized in their operation. Appropriate stress levels can be determined using the ratio of the mechanical properties of the dome casting to those of flat plates. For example, the ratio of the compressive strength of the dome casting to that of flat plate is approximately 6/7 or 0.85. Therefore, the maximum working stresses in cast domes should relate to the working stresses in domes fabricated from plates by roughly the same factor.

Since the maximum compressive working stress allowed at the present time for spherical Plexiglas manned capsules with a minimum proven 1,000 cycles and 10^5 hours static fatigue life is only 4,000 psi,* the maximum allowable compressive working stress in a cast dome having the mechanical properties shown in table 1 should not exceed 3,400 psi (arrived at by multiplying 4,000 psi by 0.85). The maximum allowable tensile working stress in a cast dome should, by the same token, not exceed 1,800 psi (arrived at by multiplying the accepted 2,000-psi value for thick plates by a factor of 0.9, the ratio of the tensile strength of a cast dome to that of typical flat plate).

In those cases where the casting does not form a dome but has the shape of a spherical sector and the design is based on empirical short-term implosion data of scale model sectors machined from Plexiglas G plates, a different approach must be used. Since the operational depth of spherical sector windows is generally only a known fraction of their short-term implosion pressure, the only modification to their design procedure is to multiply the maximum operational pressure allowed for spherical sector Plexiglas G windows by the same factor that was used in the previous paragraph to reduce allowable maximum compressive working stresses in domes.

ATTACHMENT

The attachment (figure 2) for affixing the dome to the vehicle hull has been specifically designed for shallow depths of 100 feet or less. A similar attachment could be used for depths to 1,000 feet, but the clearance between the U-shaped flange and the skirt would have to be increased to allow for greater radial contraction under the larger hydrostatic pressure.

**Based on the results of the NEMO hull testing program at the Naval Civil Engineering Laboratory, reported in references 11 through 15.*

For depths beyond 1,000 feet the cylindrical skirt and the attachment developed for it (figure 2) would have to be eliminated altogether, as the bending stresses at the intersection of the hemisphere and the cylindrical skirt become quite high. By eliminating the cylindrical skirt on the casting its operational depth can be readily increased from 1,000 feet to about 2,500 feet. For mating the hemisphere to the hull of an undersea vehicle a different attachment would have to be devised.

A typical attachment for a hemispherical dome is shown in figure A.1. Its characteristics are (1) lack of restraint to the radial contraction of the sphere under hydrostatic pressure; (2) lack of an O-ring groove under the acrylic bearing surface; (3) presence of a smooth, metallic bearing surface on which the acrylic bearing surface can slide; and (4) an externally located rubber sealing gasket.

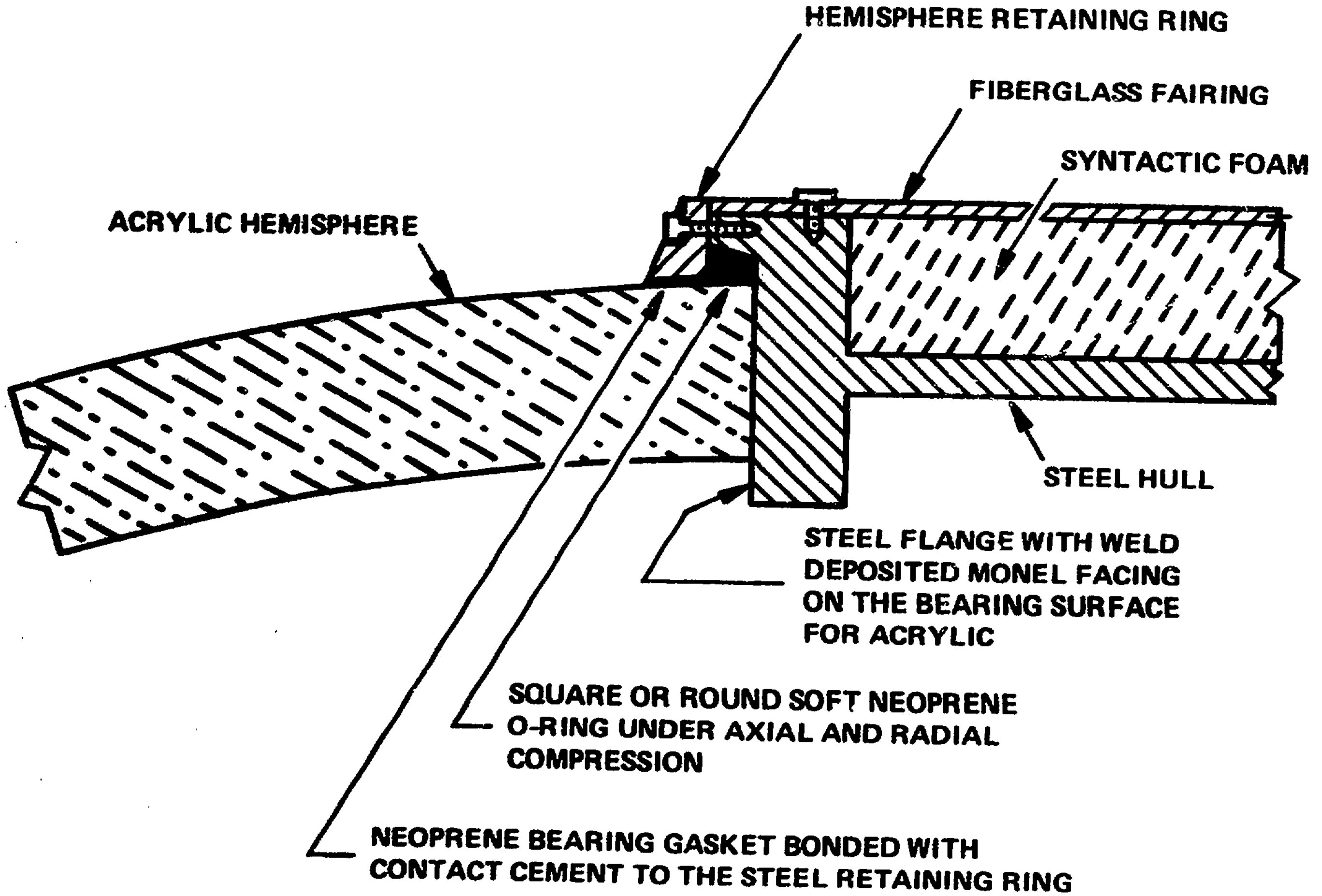

Figure A.1. Attachment for fastening a geometrically true plastic hemisphere to the hull of a deep diving submersible.

REFERENCES

1. Naval Civil Engineering Laboratory. Technical Report R-512, Windows for External or Internal Hydrostatic Pressure Vessels, pt. 1. Conical Acrylic Windows Under Short Term Pressure Application, by J. D. Stachiw and K. O. Gray. Port Hueneme, California, January 1967 (AD 646882).

2. ———— Technical Report R-527, Windows for External or Internal Hydrostatic Pressure Vessels, pt. 2. Flat Acrylic Windows Under Short Term Pressure Application, by J. D. Stachiw, G. M. Dunn and K. O. Gray. Port Hueneme, California, May 1967 (AD 652343).

3. ———— Technical Report R-645, Windows for External or Internal Hydrostatic Pressure Vessels, pt. 4. Conical Acrylic Windows Under Long Term Pressure Application of 20,000 psi, by J. D. Stachiw. Port Hueneme, California, October 1969 (AD 697272).

4. ———— Technical Report R-708, Windows for External or Internal Hydrostatic Pressure Vessels, pt. 5. Conical Acrylic Windows Under Long Term Pressure Application of 10,000 psi, by J. D. Stachiw and W. A. Moody. Port Hueneme, California, January 1970 (AD 718812).

5. ———— Technical Report R-747, Windows for External or Internal Hydrostatic Pressure Vessels, pt. 6. Conical Acrylic Windows Under Long Term Pressure Application of 5,000 psi, by J. D. Stachiw and K. O. Gray. Port Hueneme, California, June 1971 (AD 736594).

6. ———— Technical Report R-773, Windows for External or Internal Hydrostatic Pressure Vessels, pt. 7. Effect of Temperature and Flange Configuration on Critical Pressure of 90 Degree Conical Acrylic Windows Under Short Term Loading, by J. D. Stachiw and J. R. McKay. Port Hueneme, California, August 1972 (AD 748583).

7. ———— Technical Report N-1127, Flat Disc Acrylic Plastic Windows for Man-Rated Hyperbaric Chambers of the U. S. N. Experimental Diving Unit, by J. D. Stachiw. Port Hueneme, California, November 1970 (AD 716751).

8. ———— Technical Report R-631, Windows for External or Internal Hydrostatic Pressure Vessels, pt. 3. Critical Pressure of Acrylic Spherical Shell Windows Under Short Term Pressure Application, by J. D. Stachiw and F. W. Brier. Port Hueneme, California, June 1969 (AD 689789).

9. Naval Undersea Center. NUC TP 315, Acrylic Plastic Hemispherical Shells for NUC Undersea Elevator, by J. D. Stachiw. San Diego, California, September 1972 (AD 749029).

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10. ___________ NUC TP 355, Flanged Acrylic Plastic Hemispherical Shells for Undersea Systems by J. D. Stachiw. San Diego, California, August 1973 (AD 769213).

11. Naval Civil Engineering Laboratory, Technical Report R-676, Development of a Spherical Acrylic Plastic Pressure Hull for Hydrospace Application, by J. D. Stachiw. Port Hueneme, California, April 1970 (AD 707363).

12. ___________ Technical Note N-1113, The Spherical Acrylic Pressure Hull For Hydrospace Application, pt. 2. Experimental Stress Evaluation of Prototype NEMO Capsule, by J. D. Stachiw and K. L. Mack. Port Hueneme, California, October 1970 (AD 715772).

13. ___________ Technical Note N-1094, The Spherical Acrylic Pressure Hull for Hydrospace Application, pt. 3. Comparison of Experimental and Analytical Stress Evaluations for Prototype NEMO Capsule by H. Ottsen. Port Hueneme, California, March 1970 (AD 709914).

14. ___________ Technical Note N-1134, The Spherical Acrylic Pressure Hull for Hydrospace Application, pt. 4. Cyclic Fatigue of NEMO Capsule #3, by J. D. Stachiw. Port Hueneme, California, October 1970 (AD 715345).

15. Naval Undersea Center. NUC TP 305, Effect of Bubble Inclusions of the Mechanical Properties of Cast Polymethyl Metacrylate, by J. D. Stachiw. San Diego, California, August 1972 (AD 746862).