An Experimental Approach for Mould Preparation and Moulding Technique of Fresnel Lenses

D K Bandyopadhyay
Micropositioning Systems Division, Central Scientific Instruments Organization, Sector-30, Chandigarh 160 030
Received: 28 February 2002; accepted: 28 June 2002

An experimental fabrication technique of Fresnel lens master mould and the method adopted for moulding plastic Fresnel lenses is described. Fresnel lenses have concentric prismatic grooves of varying depths and angles. It is a difficult process to obtain turned metallic moulds for moulding such type of bigger size lenses. Fabrication of Fresnel lens master mould by replication technique is an attractive alternative. This paper describes how the master mould has been fabricated by copper deposition process. The selection of plastic material for lenses based on optical properties has also been enumerated.

1 Introduction

The concept of plastic Fresnel lenses is an excellent substitute to conventional glass-mirror system and is in use for long. A Fresnel lens is made out of high quality transparent plastic. It has many concentric prismatic grooves of varying depth on one side, while the other side is made flat. The prism angle gradually increases on traverse from the centre to the edge of the lens. Each groove is a minute refracting facet and is able to bend light at designated focus. The lens can be used either as a condenser or collimator.

These lenses have many advantages over conventional glass lenses. Difficulties in fabrication of huge optical glass lenses prompted for alternative plastic optics. It is estimated that 70 per cent of the moulded lenses are fabricated from plastic and the rest are made from glass. The Fresnel lenses are fabricated either by direct turning prismatic grooves on transparent plastics or on metallic surfaces. The turned metallic moulds are used to get replica of the Fresnel lens profile by injection or compression moulding. Fabrication of mould by turning is quite difficult for Fresnel lenses of bigger aperture because of low durability of available tools. It is not economical and unsuitable approach for mass production purposes. The most cost effective and alternative method for mass production of large aperture Fresnel lenses is fabrication by replication techniques. By this process, exact impression of Fresnel lenses grooved profile on electro-deposited metal surface can be achieved. An experimental approach has been made to fabricate Fresnel lens’ master mould by copper electro-deposition on an arranged plastic lens.

2 Process of Fabricating Master Mould

The master mould was prepared from an originally machine turned master Fresnel lens of required optical properties by chemically cleaning and activating the surface of the plastic lens. Then copper electroplating over the surface profile of the master lens was carried out to obtain metallic replica of the grooved surface. The thin layer of nickel deposition over the copper plated replica was done for durability, strength as well as to achieve smooth optically finished surface profile of the master mould. A schematic view of the Fresnel lens profile is shown in Figure 1.

2.1 Framing and Cleaning of Master Lens

The master lens was mounted with its flat side to a 3 mm thick plastic (Acrylic) frame with adhesive. The framed lens was cleaned and washed with cleaning solution of Zonax® cleaner 50 g/L and then it was dipped in caustic solution bath. The master lens was finally immersed for 5 min in a distilled water cleaning bath.

2.2 Activating Process

Activating of the plastic lens' grooved surface was required before silver coating operation for obtaining a fine conducting surface. Conducting activator/primer coating, consisted of 2 per cent solution of stannous chloride, which was dissolved in pre-acidified tank of water. The master lens with grooved face down was immersed and gently shaken for about 5 min. This pro-
cess was repeated 3 to 4 times. The piece was then ready for silvering operation.

2.3 Silvering Process

The silvering solution consists of the following chemicals:

1. NH₄NO₃ 7.5 g in 150 cc.
2. AgNO₃ 2.5 g in 25 cc.
3. KOH 12.5 g in 150 cc.
4. Dextrose 5 g in 50 cc.
5. Sucrose 10 g in 100 cc.

The solution of ammonium nitrate and silver nitrate are mixed in 1:6 ratio while dextrose and sucrose are mixed in 1:4 proportion. These solutions (1+2), 3, and (4+5) are mixed in 7:5:3 ratio in a beaker and transferred in a silvering tray. The tray contains the primer coated lens, immersed in distilled water at 20°C. The cooled solution produces a finer grain coating with higher mechanical density and fewer pinholes. The tray is shaken gently for even distribution of solutions over the lens' grooved surface. The silver layer coating process was repeated for ten times for considerable thick layer of silver over the lens surface. After silver coating was finished the coated lens was dried up and checked for any discontinuation of the silver coated layer. Any blow hole may lead to improper electroplating.

2.4 Copper Electroplating

It was necessary to have a solid smooth profile of grooved Fresnel lens surface on metal for plastic moulding. For getting the true copper replica of the Fresnel lens' prismatic grooved profile over the silver coated master lens, copper electroforming process was adopted. An acid-solution bath was used for depositing copper over the activated lens surface. To obtain finer copper deposition in the beginning, low metal and acid contents were maintained in the bath. The resistivity of the bath diminished due to non-formation of basic salts in the presence of H₂SO₄ and CuSO₄. This results in low copper ion concentration and extends a good quality copper deposition on the silver coated Fresnel lens surface.

An outstanding feature of the acid copper electroforming process is that the replication of the intricate detail is extremely fine. The reason for using copper plating as undercoat for nickel is that the process is easy, accurate, and economical.

A pure copper plate (99.9 per cent Cu) was used as anode. The size of the copper plate was taken same as
coated lens surface for even and homogeneous distribution of copper deposition. Silver coated lens was taken as cathode. Both were positioned 15 cm apart in the acid-bath, as shown in Figure 2. In the beginning of the electroforming process the concentration of the acid copper solution is taken as CuSO_4 - 60 g/L, H_2SO_4 - 2 g/L at ambient temperature. Current density 0.54-1.0 A/dm² is maintained in the electrodes for 3 min. This process is able to generate a fine smooth layer of copper coating on activated plastic lens surface. For thicker copper plating, another acid copper bath of the following measurements was used:

<table>
<thead>
<tr>
<th>Compound</th>
<th>g/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper Sulphate</td>
<td>200</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>50</td>
</tr>
<tr>
<td>Temperature</td>
<td>25 - 30°C</td>
</tr>
<tr>
<td>Current density</td>
<td>2.2-2.7 A/dm²</td>
</tr>
</tbody>
</table>

The acid bath was ceramic lined. Sulphuric acid was added slowly in large volume of water in the bath. The current was raised to about 25 A stepwise. The deposition rate was kept at 0.2 mm/h. To get about 3 mm thick plating the electrolytic process continued for 15 h. After the desired thickness was obtained the electroformed piece was removed from the bath and washed in distilled water. Removal of electroplate from original master lens’ surface was done by milling about 1 mm from four sides of the copper deposits. As original master lens was made of acrylic and was self-lubricated, there was no possibility of sticking the electroplated part with master lens. Then the electroformed surface was etched in an acid bath for removing silver layer and to obtain brighter copper surface before placing the electroform for nickel coating.

2.5 Nickel Coating

Nickel coating over copper replica of Fresnel lens was necessary for surface hardness, durability, corrosion resistance, and shining profile of the grooved surface. Certain percentage of brightener agent was added to nickel coating solution for better brightness and leveling, which helps to get smoother surface.

The composition of nickel bath solution was kept as:

<table>
<thead>
<tr>
<th>Compound</th>
<th>g/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel Sulphate</td>
<td>240</td>
</tr>
<tr>
<td>Nickel chloride</td>
<td>30</td>
</tr>
<tr>
<td>Boric acid</td>
<td>30</td>
</tr>
<tr>
<td>Nickel format</td>
<td>45</td>
</tr>
<tr>
<td>Cobalt Sulphate</td>
<td>2.6</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>2.5</td>
</tr>
<tr>
<td>Ammonium Sulphate</td>
<td>0.8</td>
</tr>
</tbody>
</table>

The current density was maintained at 2.2-5.4 A/dm² and temperature of the bath solution kept about 45°C for higher efficiency of deposition. The thin layer of 12 μm bright nickel deposition was achieved within one-and-half-hour of electrolytic process. The nickel coated copper replica was taken out from nickel bath. The electroform was cleaned for fixing with base plate for getting a master mould.

2.6 Fixing of Electroform

Fixing of electroplated replica with a 12mm thick brass plate was done by special adhesive. The adhesive had heat curing temperature of 120°C. A thin layer of adhesive was evenly spread over the back surface of the replica and base surface of brass plate. For proper bonding with base plate the electroplated replica was kept inside an oven for 2h. under uniformly distributed pressure over the surface of the replica. The temperature of the oven was maintained at 120°C. After this the bonded replica with base plate was removed for riveting. The riveting was done along the ungrooved periphery of the electroplated master mould and machining of edges was carried out. The master mould was optically polished before compression moulding of acrylic Fresnel lenses.

3 Selection of Moulding Material

It is very important to identify proper moulding material for getting moulded Fresnel lenses. The material should have very good optical properties. It was observed that acrylic resins (Polymethyl methacrylate) is an excellent transparent plastic with refractive index better than glass. This material has good dimensional stability.
in the presence of sunlight and having a high degree of heat resistance. This is a thermoplastic substance and it can be reused for moulding. This acrylic resin is generally used for moulding in granular form.

Physical properties of polymethyl methacrylate are:
- Index of refraction = 1.49
- Luminous transmission = 92 per cent
- Specific gravity = 1.18
- Thermal conductivity = 4 to 6 kcal/gm/sq.cm/°C/cm
- Heat resistance = 105°C
- Moulding temperature = 120°C to 270°C
- Absorption (Per cent H₂O/h) = 0.03-0.04
- Tensile strength = 5.5 x 10³ N/cm²
- Compression strength = 10.5 x 10³ N/cm²
- Rockwell hardness = M95

4 Hydraulic Press
The semi-automatic hydraulic press was used for the production of Fresnel lenses. The press was of vertical four-column design with top pressure. The working speed was controlled by means of the throttle valve, at arbitrary position of the platen. When reducing the working speed, escape of air from the mould was enabled and thus the number of damaged moulded parts during the ejection is decreased.

Technical data of the hydraulic press used:
- Maximum working powerR = 250 T
- Return power = 125 T
- Area of bed = 1000 x 1000 mm
- Diameter of working piston = 325 mm
- Stroke = 600 mm
- Day light = 1200 mm

5 Moulding Arrangements
For fabrication of Fresnel lenses from acrylic thermoplastic material, it was required to heat up the plastic granules over the master mould. After compression process the mould should be cooled down to about 40°C for ejecting of the moulded parts. For these purposes, four plates were fabricated, two for heating and other two for cooling the mould.

5.1 Heating Plates
There are two heating plates one for upper half of the press and another for lower half. The two heating plates were of mild steel, having size 400x375x50 mm each. Nine holes on the plates were drilled for provision of cartridge type heating units, as shown in Figure 3. The rod shaped cartridges of 1000W each were inserted into the plugged holes. The correct moulding temperature was calculated and uniform distribution of heat over the plate was ensured for proper formation of the moulded parts. The plastic granules used, needed approximately 180°C, for compression moulding. The thermostat controller was used to control the desired temperature of the heating plates.

5.2 Cooling Plates
Two cooling plates were fabricated exactly of the same size as heating plates. They were individually mounted over each heating plate. These plates were designed in such a way to expedite cooling process of the moulded parts. The cooling plates having uniformly distributed cooling water supply are shown in the Figure 4.
5.3 Press Plate

A press plate or punch plate of high chromium alloy tool steel was cut as per the size of the master mould. One of the surface of the press plate was optically mirror polished so that there should not be any patch mark during moulding process. The optically polished surface facing downward was mounted on the upper half on the cooling plate.

5.4 Mounting Process

The master mould was placed over the cooling plate on the lower half of the press. The schematic view of the moulding setup is shown in Figure 5. One brass ring was placed around the periphery of the master mould to guide the acrylic granules. Care was taken to properly position the ring with the help of guide pins. Silicon spray may be applied over the grooved surface of the
mould, before moulding processes nonsticking agent. The measured amount of acrylic granules are spread evenly over the grooved surface of the mould. The acrylic granules were pre-heated for evaporating any moisture.

6 Moulding Process

After suitable pre-heating the press plate was allowed to make contact with the master mould and was heated up to 170°C. The pressure applied was 135 T for 5 min on 300 X 300 mm mould. All the heaters were put off and cooling process started. Pressure of the press plate was then released but contact between mould and press plate remained intact until master mould cooled down to 40°C. The upper press plate was allowed to move upward and the moulded plastic lens was then removed easily with the help of ejection pin. The moulded part took the shape of original grooved surface of the Fresnel lens.

7 Conclusions

One fabricated Fresnel lens was arranged for solar energy condenser and taken as master lens for experimental purpose. The lens size was 300 sq. mm, and focal length 380 mm. The moulded Fresnel lenses were then tested for their focal length and image clarity. They were found to be very good in performance.

One master mould fabricated by this process has substantial repeatability and can be used for moulding 100 - 150 Fresnel lenses. The quality of the plastic moulded lenses, virtually related to proper activation of the master lens, superior electroforming and overall proper moulding technique. The fabrication processes are easy and suitable for bigger size lenses with short focal length. It can be concluded that the Fresnel lens master mould developed by electroforming technique is an excellent substitute for costly imported unit.

References