

A stainless-steel mandrel for slumping glass x-ray mirrors

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ABSTRACT

We have fabricated a precision full-cylinder stainless-steel mandrel at Marshall Space Flight Center. The mandrel is figured for a 30-cm-diameter primary (paraboloid) mirror of an 840-cm focal-lengthWolter-1 telescope. We have developed this mandrel for experiments in slumping—thermal forming at about 600°C—of glass mirror segments at Goddard Space Flight Center, in support of NASA’s participation in the International X-ray Observatory (IXO). Precision turning of stainless-steel mandrels may offer a low-cost alternative to conventional figuring of fused-silica or other glassy forming mandrels. We report on the fabrication, metrology, and performance of this first mandrel; then we discuss plans and goals for stainless-steel mandrel technology.

INTERNATIONAL X-RAY OBSERVATORY

The International X-ray Observatory (IXO), next-generation astronomical X-ray Mission, requires extremely large collecting area (3 square meters of effective area at 1 keV and 1 square meter at 6 keV) combined with good angular resolution (5 arc-sec half power diameter) in order to achieve unprecedented sensitivities for the study of the high-z Universe and for high-precision spectroscopy of bright X-ray sources. Slumping glass technology is one of the fabrication techniques considered for producing the x-ray mirror segments for a single large x-ray mirror assembly. This mirror fabrication approach requires massive number of the forming mandrels. Stainless-steel mandrels may offer a low-cost alternative to conventional figuring of fused-silica or other glassy forming mandrels.

Stainless Steel Mandrel

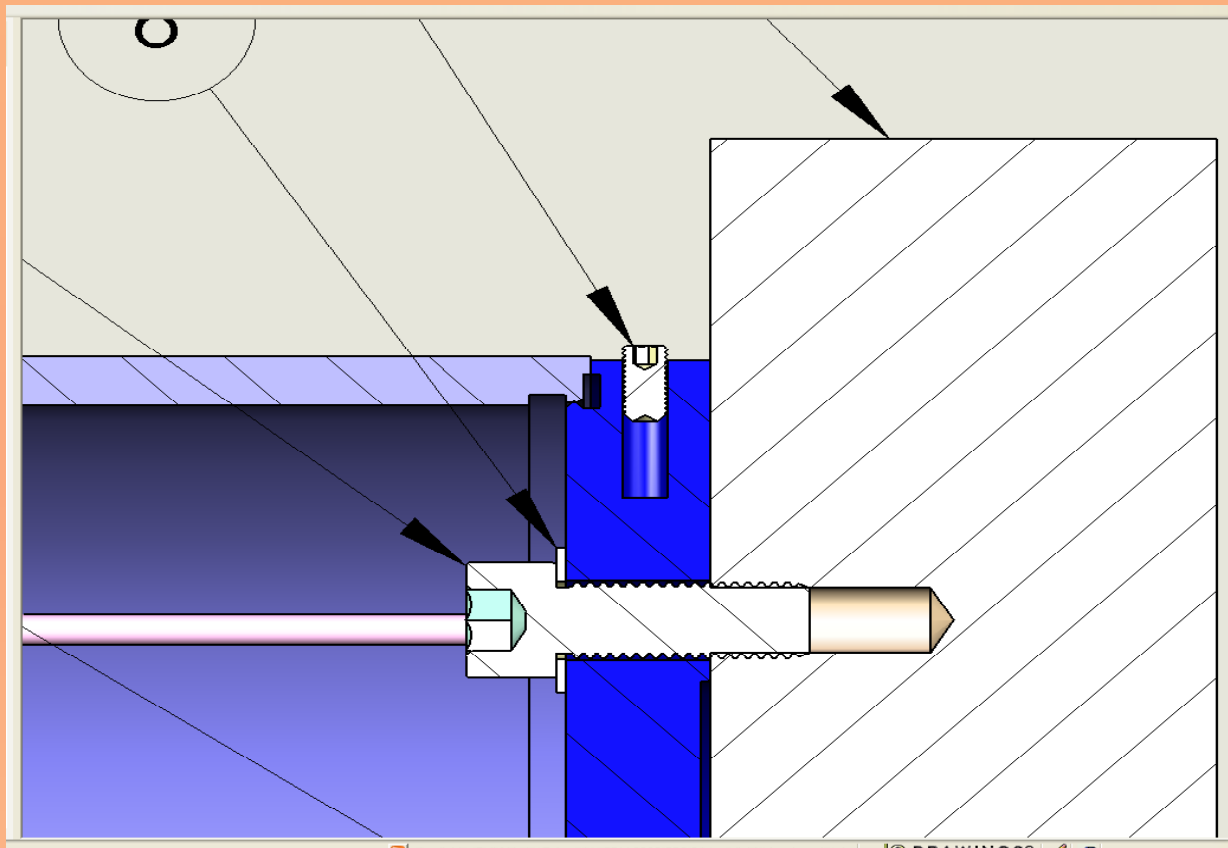
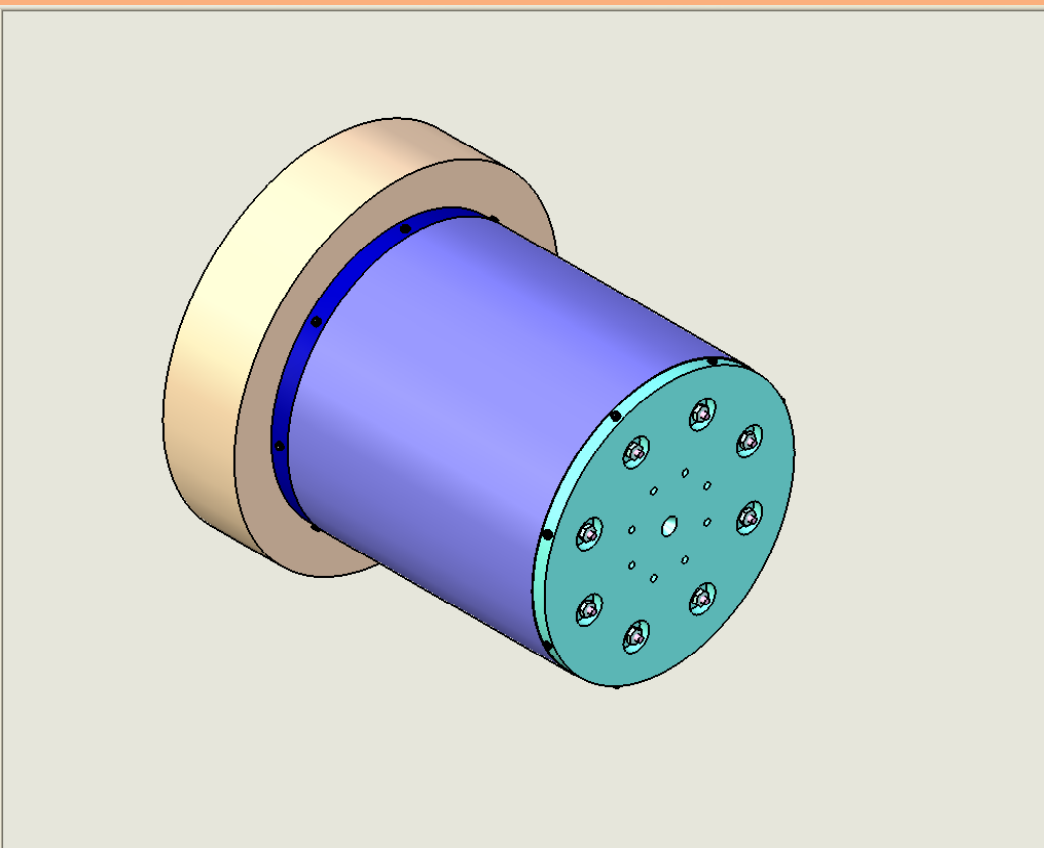
Goal:

Find commercially available material applicable for manufacturing of the forming mandrels to significantly reduce cost of the glass replication process

Mandrel description

- 8400 mm focal length
- 155.080 mm intersection plane radius
- 304.8 mm overall length (12.000 inches)
- 200 mm optical length (50 mm zone at each end for polishing overstroke)
- Performance prediction requirement – 15 arc seconds (HPD)

Material: 304L Stainless Steel
– 18-20% Cr, 8-12% Ni
– 0.03% C,1% Mn, 1% Si, 0.045% P, 0.03% S, 0.1% other



Mandrel support design

Mandrel Fabrication

- Rough machining – Heat Treatment – Precise machining – Initial Precision turning
- Axial Figure Metrology – Final Precision Turning – Polishing – Final Metrology

- Design of the support structures for machining, turning and polishing - Precision fit.
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- Thickness of the mandrel was set to 1 cm based on thermal considerations.



The mandrel on precision turning machine

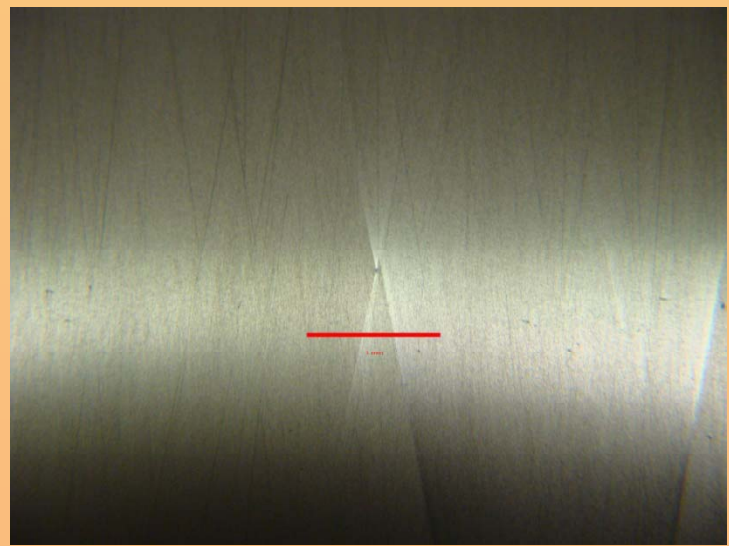
Mandrel Fabrication (cont.)

Pre-machining and precise turning:

- The mandrel was stress relieved at 650°C for one hour. The stress relieving temperature is much lower than annealing temperature (1010 to 1120 °C), so grain growth should not be an issue.
- Rough machining went fine, but the mandrel was warped after heat treatment. Contractor has performed the precise machining;
- “Free standing” mandrel is out of roundness;
- Mandrel was turned on inside to make it to conform to the end rings better;
- All mandrel assemblies were done at the Circularity Test Stand.

Polishing:

- The hardened steel layer has appeared during initial polishing. The mandrel was precision grinded.
- At the point of final polishing pull-outs became visible (possibly the result of the precision turning)
- The mandrel was precision grinded again
- The mandrel is polished to 45A rms



An example of the mandrel surface “pull-ups”



Stainless Steel Mandrel at Coordinate Measuring Machine



The mandrel during the axial figure measurements using the Vertical long trace profilometer.

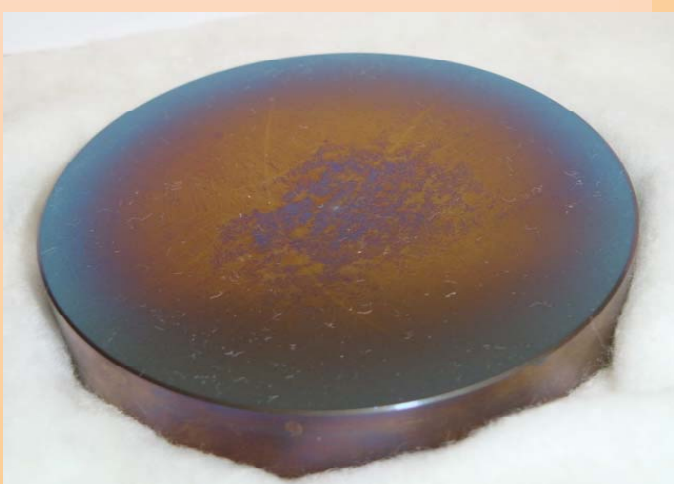
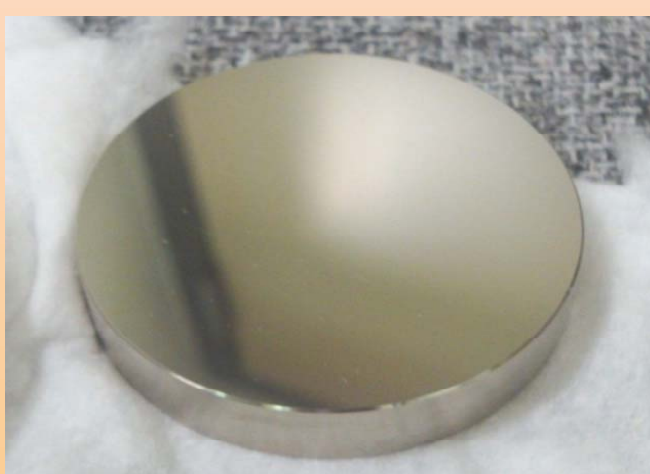
Metrology and Analysis

- Circularity Test Stand – for azimuthal variations of radius and cone angle
- Vertical Long Trace Profilometer - for axial slope deviations
- Coordinate Measuring Machine - for absolute radius and mean cone angle

Predicted Angular resolution (HPD), 2 reflections

| Meridian | 0° | 45° | 90° | 135° | 180° | 225° | 270° | 315° | All 8 |
|----------------------------|------|------|------|------|------|------|------|------|-------|
| Axial HPD ₂ ["] | 6.08 | 6.49 | 7.23 | 4.85 | 5.07 | 5.05 | 7.24 | 6.77 | 6.13 |
| Cone HPD _{G2} ["] | 6.39 | 1.49 | 3.93 | 1.25 | 2.57 | 4.93 | 6.80 | 3.75 | 7.28 |
| Total HPD ₂ ["] | 8.83 | 6.66 | 8.23 | 5.01 | 5.68 | 7.06 | 9.94 | 7.74 | 9.52 |

Surface Passivation



- Surface of SS coupon degraded during thermal cycling
- A surface passivation study has been performed. Two techniques have been tested: the electro-chemical passivation and nitric acid passivation.



Results:
Nitric acid passivated stainless steel coupon (left photo) – the surface roughness degraded from 46 to 168 A after the heat treatment;

Electrochemically passivated stainless steel coupon (right photo) – the surface roughness degraded from 23 to 1068 A after the heat treatment.

Future Plans

- Thermally cycle the mandrel. Perform full metrology on the heat treated mandrel to characterize possible changes in mandrels figure, circularity and surface roughness;
- Resume fabrication process study with coupons in order to define an ideal stainless steel for mandrel production;
- Produce hyperbolic mandrel to match the primary mandrel.