Ultra-Precision Machining of Aspheric Molding Dies for Future Hard X-ray Telescope Missions

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1. Introduction

Following the launch of ASTRO-H in 2015 [1], there are currently no plans for sending other X-ray telescope missions into space. Before a new mission can be envisaged, it will be necessary to demonstrate technology for making thin X-ray mirrors with higher accuracy and more economically than in previous missions.

Two replication methods have been proposed for this purpose. The first one is based on diamond turning of electroless nickel plated aspheric molding dies, for mirror replication by DC magnetron sputtering [2].

The other method is based on slumping of super-smooth thin LCD glass over fused silica molding dies [3] (see Fig. 1). It has been proposed as an economical solution for producing aspheric X-ray mirrors, with shape deviation less than 100nm P-V. In this paper, the methodology and metrology used for deterministic finishing of fused silica mandrels are described.

Fig. 1. Slumping process for 0.2mm thick LCD glass over fused silica mandrel.

2. Methodology

In order to produce a demonstration mandrel with focal length 8.4m, blocks of fused silica were manufactured and precision ground in industry to the approximate aspheric shape (see Fig. 2). The shape deviation after grinding was measured with a UA3P CMM at the Panasonic factory in Osaka.

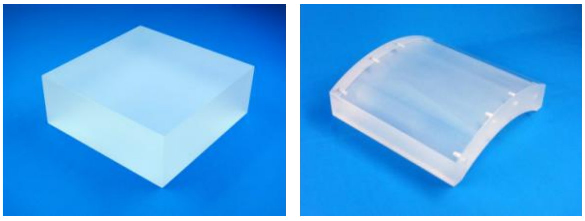

Fig. 2. Block of fused silica, before and after precision grinding of the aspheric shape.

A special measurement jig was made (see Fig. 3), to create a reference frame attached to the physical centre and orientation of the mandrel (by intersecting the lines passing through the centers of 4 Silicon Nitride balls).

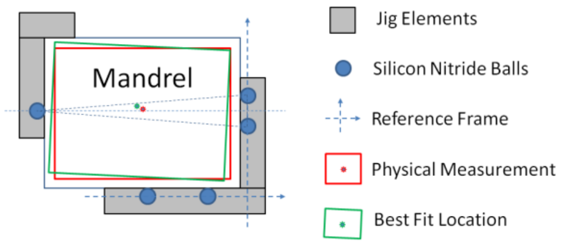

Fig. 3. Jig for referencing the best fitted error.

The centre point was then referenced against this frame using a 5th ball on the opposite side of the mandrel (used to measure the exact width and length, which were then divided by 2). The position of the best-fitted shape deviation was referenced relative to this point.

After determining the relative location of the best fitted error, this information was input into numerical optimization software that combined it with data about polishing removal rates to derive deterministic tool paths capable of reducing the form error [4]. This tool path was run on a 7-axis CNC machine built by Zeeko (see Fig. 4).

Fig. 4. Fused silica mandrel being deterministically polished inside 7-axis CNC machine.

3. Finishing Progress

The initial aspheric form error of the ground mandrel was 36.7 um P-V. The mandrel was polished using the process parameters shown in Table 1. The surface feed of the polishing spot was moderated between 100 and 3000 mm/min in order to improve the form. The intermediate result after 5 correction runs is displayed in Fig. 5, showing improvement down to 0.35 um P-V.

Table 1. Process parameters of polishing runs.

Workpiece	Fused Silica
Polishing tool Radius Cloth	Precessed bonnet 40 mm Poromeric felt
Tool-path mode Point spacing Tool offset Head speed Precess angle Surface feed	Raster 1.0 mm 0.6 mm 2000 rpm 20 deg 100~3000 mm/min
Abrasives Grain size Density	CeO_2 (1.5 um) 1.5 µm 60g/L

Intermediate surface roughness was measured with a white light interferometer at 0.6 nm rms (see Fig. 6), which is adequate for slumping.

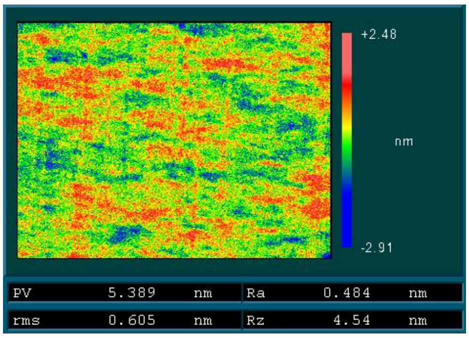

Fig. 6. Intermediate roughness (rms 0.6nm).

4. Conclusion

In this paper, progress on an innovative method for replication of thin X-ray mirrors using slumping over Fused Silica mandrels was reported. An aspheric fused silica mandrel has been ground and correctively polished from ~36 um down to ~0.3 um P-V of shape deviation. Corrective polishing will carry on until reaching <100 nm P-V. The intermediate surface roughness of 0.6nm rms is adequate for replication by slumping method.

Acknowledgments

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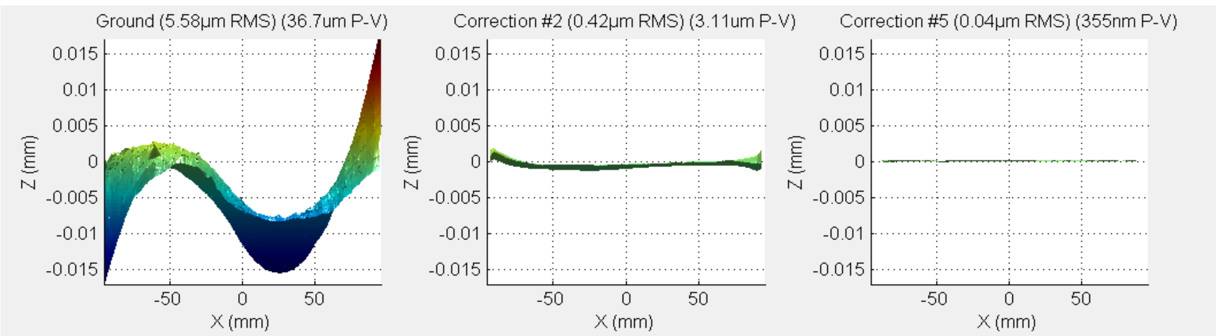

Fig. 5. Left: Form deviation after grinding (36.7um P-V). Right: after 5 polishing runs (0.35um P-V).