Surface polishing characteristics of ultrafine-grained aluminum alloy for reflective optics of infrared hyperspectral imaging.

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Abstract. The integral field unit (IFU) is a hyperspectral imaging instrument developing for infrared astronomy. The IFU mainly consists of three mirror arrays with complex shapes (slicing mirrors, pupil mirrors and slit mirrors), which require high form accuracy (< 0.1 μm PV) and high quality surface finish (< 5 nm Ra). The mirrors have a monolithic structure of ultrafine-grained aluminum alloy to prevent thermal deformation by bimetal effect under liquid nitrogen temperature. In previous research, we fabricated slice mirror allays by ultraprecision shaper cutting, surface roughness was insufficient and tool marks remain on fabricated surface. We are planning to adopt surface polishing process after ultraprecision cutting by a single crystal diamond tool to eliminate cutter mark and improve surface roughness less than 5 nm Sq. Preliminary polishing experiments of ultrafine-grained aluminum alloy are conducted using a flat polishing pad and alumina or diamond slurry in various conditions such as rotation speed, pressure and slurry. The surface roughness of finished surface was 1.84 nm Ra. The result was compared to other aluminum alloys with different compositions.

Introduction

The integral field unit (IFU) for Simultaneous-color Wide-field Infrared Multi-object Spectrograph (SWIMS) [1] is a hyperspectral imaging instrument developing for infrared astronomy (Fig. 1). The IFU mainly consists of three mirror arrays (Fig. 2) with complex shapes (slicing mirrors, pupil mirrors and slit mirrors), which require high form accuracy (< 0.1 μm PV) and high quality surface finish (< 5 nm Ra). The mirror arrays are preferred to have a monolithic structure since the not only superior form accuracy but also strict position and orientation accuracy of each mirror facets. Although ultraprecision diamond cutting technique using nickel phosphorous amorphous plating [2, 3] is most promising to fabricate the precise and complicated optics like mirror arrays, thermal deformation by bimetal effect between nickel layer and its substrate is unavoidable under liquid nitrogen temperature.

In previous research [2], we adopted melt span ultrafine-grained aluminum alloy (RSP Technology) [4] as material for the mirror arrays to prevent bimetal effect and fabricated slice mirror allays by ultraprecision shaper cutting. As the result of the studies, surface roughness was insufficient (> 5 nm Ra) and tool marks remain on fabricated surface.

We had investigated surface polishing characteristics of melt span ultrafine-grained aluminum alloy for reflective optics of infrared hyperspectral imaging. The surface roughness was compared between conventional and ultrafine-grained aluminum (Table 1.)

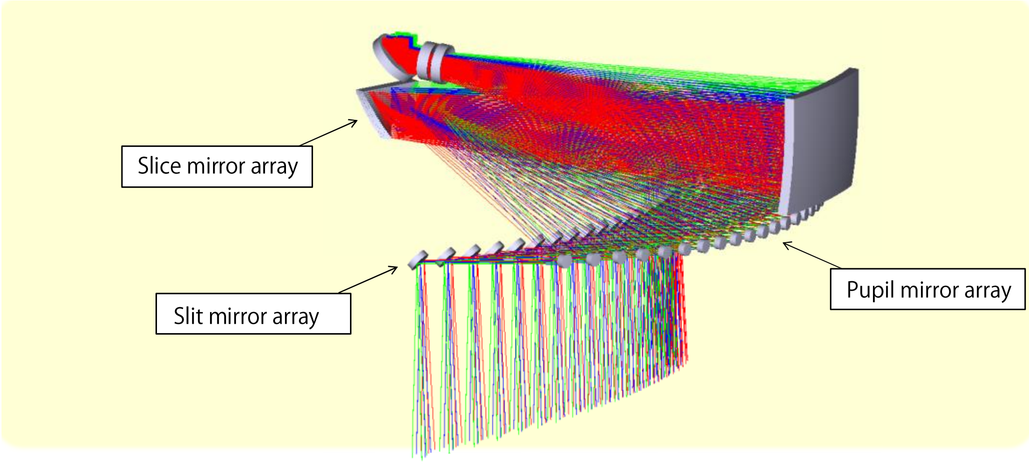


Figure 1. Optical design of Integral Field Unit (IFU) for Simultaneous-color Wide-field Infrared Multi-object Spectrograph (SWIMS) [1].

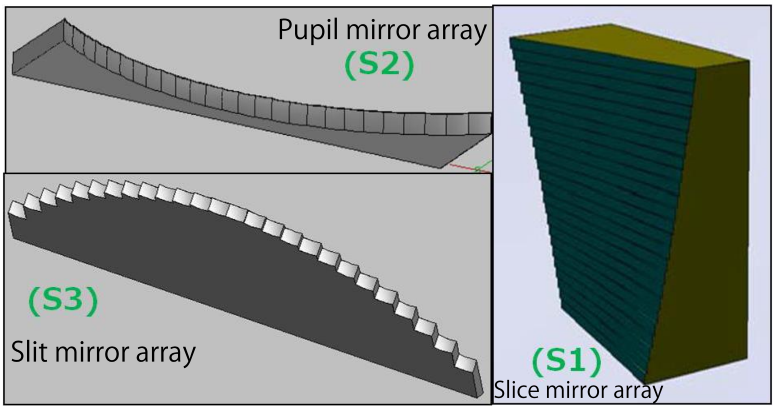


Figure 2. Three types of mirror arrays for SWIMS-IFU, Slice mirror array (S1), Pupil mirror array (S2) and Slit mirror array (S3) [1].

Table 1. Aluminum alloys and their compositions.

Aluminum alloy	Composition [%]
RSA-405 (R4)	Si 40
RSA-6061(R6)	Si0.6 Cu0.3 Mg1
RSA-905 (R9)	Fe2.5 Ni5 Cu2.5 Mn1 Mo0.8 Zr0.8
AA-2017 (A2)	Si0.2-0.8 Fe0.7 Cu0.40-1.0 Mn0.4-1.0 Mg0.40-0.8 Zn0.25 Cr0.10 Zr＋Ti0.20
AA-5052 (A5)	Si0.25 Fe0.40 Cu0.10 Mn0.10 Mg2.2-2.8 Zn0.10 Cr0.15-0.35
AA-6061 (A6)	Si0.40-0.8 Fe0.7 Cu0.15-0.4 Mn0.15 Mg0.8-1.2 Cr0.04-0.35 Ti0.15
AA-7075 (A7)	Si0.30 Fe0.5 Cu1.2-2.0 Mn0.30 Mg2.1-2.9 Zn5.1-6.1 Cr0.18-0.35 Zr+Ti0.25

Polishing conditions. For the preliminary investigation of polishing characteristics of micro-grained melt span aluminum alloy, flat polishing experiments was conducted using desktop single-side polishing machine (Maruto Co., Ltd.|). Table 2 describes the conditions of flat polishing experiment. Alumina polishing suspension (3, 0.1, 0.05µm dia.), diamond slurry (0.5 µm dia.) or chemical polishing solution were dropped on a woven polishing cloth polishing pad, which drop rate was 0.67 ml/min. The material of workpieces was one of conventional (A2, A5, A6, A7) and ultrafine-grained aluminum alloy (R4, R6, R9). The workpiece were formed to cylindrical shape which are 20 mm diameter and 20 mm height. Before polishing experiments, each workpieces were ground for 10 min by # 2,000 silicon carbide grinding papers for the preparation before the polishing experiments.

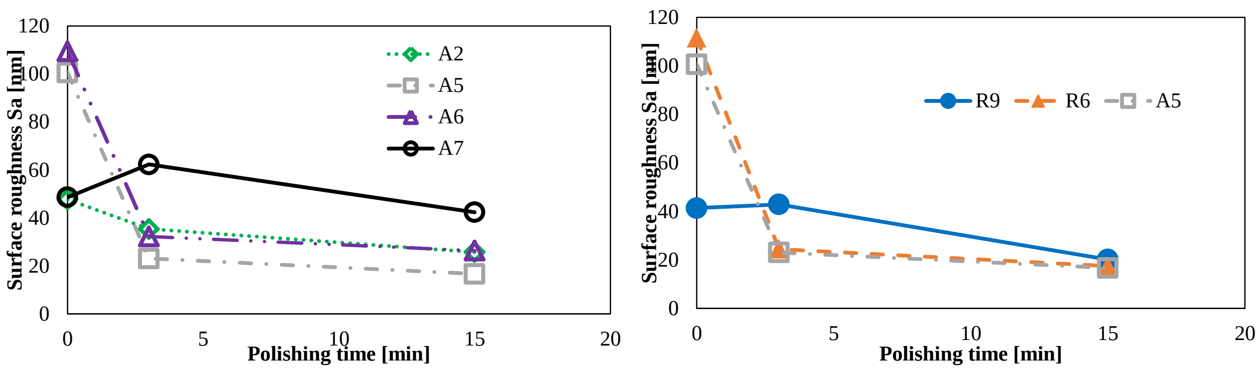
Table 2. Polishing conditions.

Slurry	alumina polishing suspension (3, 0.1, 0.05µm), 0.5µm diamond slurry, chemical polishing solution
Polishing pad	woven polishing cloth (soft)
Polishing machine	Desktop single-side flat polishing machine (Maruto Co., Ltd.|)
Rotation speed [min^{-1}]	92
Pressure [kPa]	10.27, 5.59, 2.25
Supply of slurry [ml/min]	0.67
Workpiece	Cylinder: 20mm diameter, 20mm height conventional aluminum alloy (A2, A5, A6, A7) or ultrafine-grained aluminum alloy (R4, R6, R9)

Measurement of polished surface. Surface morphologies were observed using a differential interference contrast (DIC) microscope (Olympus BX). A white-light fringe-scanning interferometric microscope (ZYGO ZeGage plus, 0.01nm resolution) has been used for roughness measurement of polished flat surface.

Results

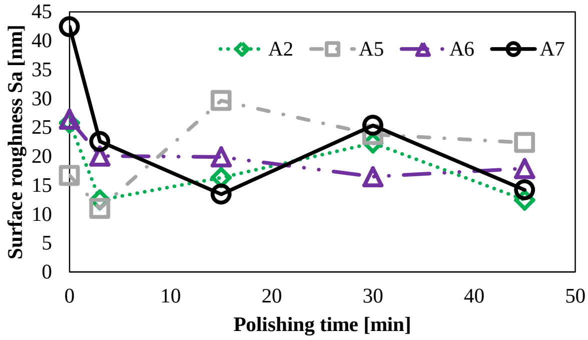
3 µm alumina polishing. After 10min #2000 SiC paper grinding, polishing experiments by 3 µm alumina suspension slurry are performed. Polishing pressure is 10.27kPa, rotation rate is 92 min^{-1} and a supply rate of aluminum slurry is 0.67ml/min. Fig. 3 shows surface roughness according to polishing time. Although, only in case of A7, surface roughness increases after 3min polishing (Fig. 3 (a),) roughness of all workpieces improves after 15 min.

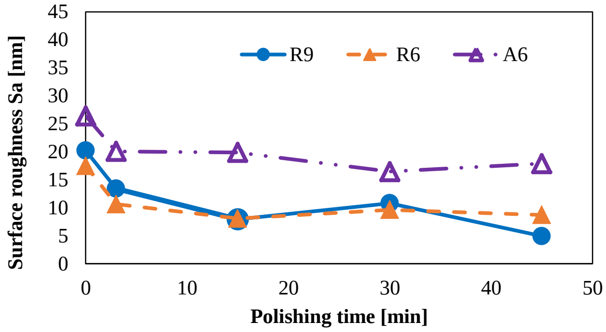


(a) Conventional aluminum (A2, A5, A6, A7) (b) Melt span aluminum alloy (R9, R6).

Figure 3. Surface roughness results according to polishing time using 3 um alumina slurry.

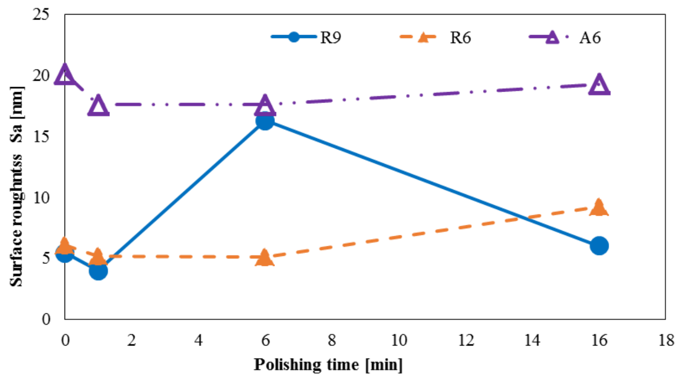
0.1 μm alumina polishing. After 3 μm alumina polishing in 15 min, polishing experiments by 0.1 μm alumina suspension slurry is conducted for 45 min. Other conditions are identical to previous experiments. Fig. 4 shows surface roughnesses according to polishing time. R9 and R6 reached less than 10 nm surface roughness in Sa after 15 min polishing while that of all conventional alloys is over 10 nm Sa.



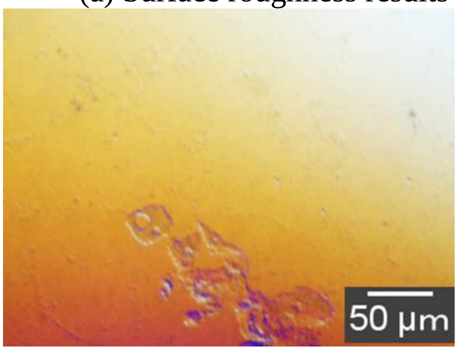


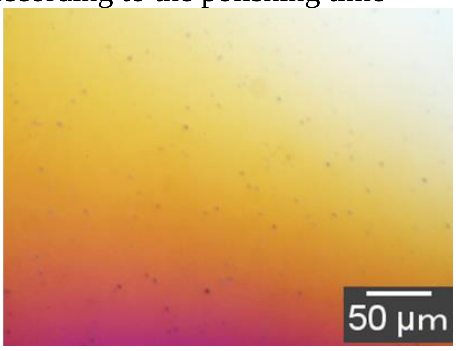
(a) Conventional aluminum (A2, A5, A6, A7) (b) Melt span aluminum alloy (R9, R6).
Figure 4. Surface roughness results according to polishing time using 0.1 um alumina slurry.

Corrosion by chemical polishing solution. Aiming better surface quality, chemical polishing solution are applied this polishing procedure (Fig. 5.) Polishing time is 10min, Pressure is 10.27kPa and rotation speed is 92 min^{-1}. The surface roughness of R9 after 6 min was degraded over 15 nm apparently (Fig. 5(a).) Surface defects by corrosion were observed on the polished surface of R9 (Fig. 5(b).)



(a) Surface roughness results according to the polishing time





(b) surface morphology of R9 after 6 min (c) surface morphology of R6 after 6 min
Figure 5. Surface roughness and DIC microscopic surface morphology in polishing R9, R6, A6 using chemical polishing solution

Comparison of finishing procedure. In order to investigate finishing condition, surface roughness was compared between three types of polishing slurry, 0.05 µm alumina, 0.5µm diamond and chemical solution (Fig. 6, 7) using R9, R6 and A6. In case of 0.05 µm alumina for A6 material, surface roughness increases after 50 min polishing once. It is supposed that inhomogeneity of surface material in A6 causes polishing rate dispersion. 0.05 µm alumina for R9 material and 0.5 µm diamond is superior at this condition respectively in the viewpoint of surface roughness and its convergent rate.

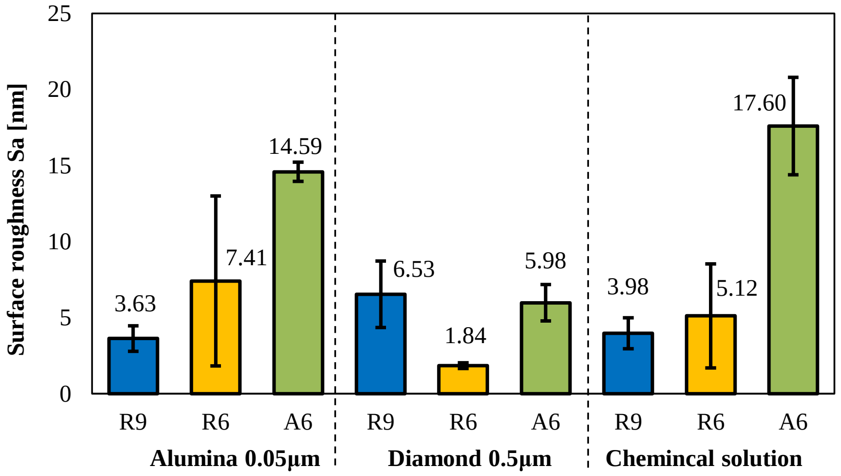


Figure 6. Comparison between 3 different polishing slurry in polishing R9, R6 and A6

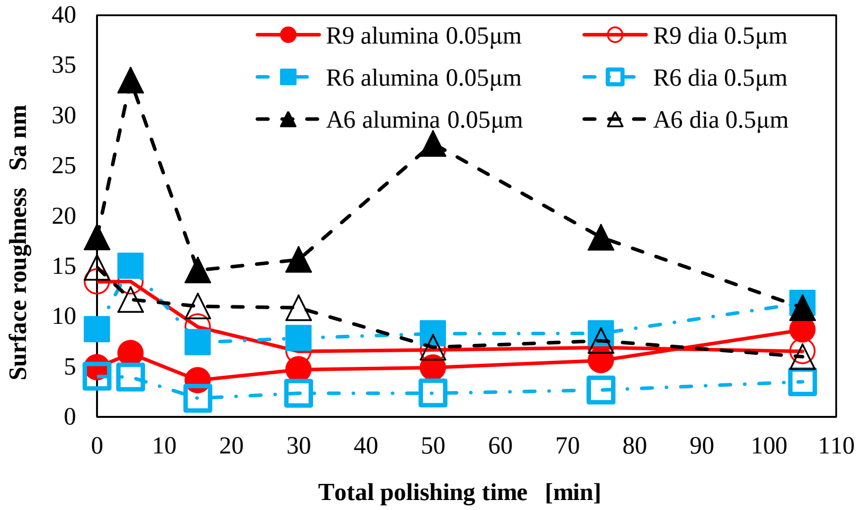


Figure 7. Surface roughness results according to the polishing time in polishing R9, R6 and A6.

Conclusion

The present results suggested that ultrafine-grained aluminum alloy R6 and R9 have excellent machinability not only for ultraprecision diamond cutting, but also for ultra-smooth fine polishing. This implies that R6 and R9 are applicable to the material of monolithic slice mirror allays for SWIMS-IFU. Further studies are needed in order to improve surface roughness (< 1nm Sa) and develop polishing technique with a small polishing tool for the complicated structure of the mirror arrays.

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