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DEVELOPMENT OF POLISHING TECHNOLOGY USING HEAT FOR MIRROR-LIKE SURFACE OF ALUMINUM

Recently, high efficient solar power generation is required because eco-awareness is increasing. High efficient generation becomes possible by focusing sunlight on electric generating element, i.e. CPV (Concentrator photovoltaic). Although the concentrator is used for focusing sunlight, it demands large spherical surface with high solar reflectance, fine accuracy and lightweight. Aluminum is considered as suitable material for concentrator. However, mirror-like processing on large spherical surface is very difficult. Therefore, new polishing technology for aluminum was developed and evaluated in this paper. Main objective is to obtain high solar reflectance by improving surface roughness. As a trial study, workpiece was not large spherical but small and flat. Firstly, the polishing tool which attached polishing cloth was developed. Optimum polishing cloth for tool was investigated by trial and error approach. When workpiece was heated before starting polishing, a number of oxides were adhered to polishing cloth and surface roughness was improved efficiently. Then optimum polishing condition was decided by using design of experiments method. Finally, solar reflectance on polished surface was measured and evaluated. It is concluded from these results that (1) the developed polishing technology was effective for processing the mirror-like surface on the surface of aluminum, (2) 82% solar reflectance was obtained with developed polishing technology by improving surface roughness of workpiece.

1. INTRODUCTION

Environmental protection activities are frequently being conducted because many environmental problems such as global warming are taking place in the world. Moreover, it is one of very important matter to ensure steady supply of electric energy without generating CO_2 emissions. Although development of renewable energy are actively carrying out [1],[2], solar power generation have a lot of attention as one of renewable energy technology. As electricity generation is gradually increasing in the world [3], there is increasing interest in high efficient solar power generation in recent years. High efficient solar power generation becomes possible with focusing sunlight on a single center of electric generating element, it is so-called CPV [4],[5]. Concentrator is used for focusing sunlight and aluminum is suitable for it because it is relatively light material and has high

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specific strength. Concentrator has large spherical surface, which diameter is more than 1m, and it needs high reflectance for high efficient solar power generation. Although mirror-like processing is necessary for concentrator to obtain high reflectance, it is very difficult because there is no machine tool for it.

On the other hand, mirror-like surface is required to manufacture high quality products. Polishing is frequently used for the mirror-like processing. High speed and fine polishing technology using linear motor was developed [6]. Furthermore, the new polishing tool which consists of several polishing units was developed for automatic polishing system [7]. Although this polishing system was applied to aluminum, surface roughness was not sufficiently improved, then Rz (maximum height) was 0.63μm. Generally, surface roughness of mirror-like surface is less than or equal to 0.1 μm, which is less than or equal to a quarter of visible wavelength. Although a research using gelatin-based stone is carrying out, it cannot obtain mirror-like surface [8]. And electrolytic polishing without using harmful substance was also developed [9]. However, large treatment equipment is required. Although magnetic abrasive polishing is being investigated [10],[11], it still has not obtained an adequate surface roughness.

Therefore, a new polishing technology for aluminum was developed and evaluated in this paper. Aim of this paper is to obtain the high solar reflectance by improving surface roughness of concentrator which consists of aluminum. It is expected that high efficient solar power generation becomes possible with increased solar reflectance of concentrator. Although actual concentrator is large and spherical surface, small and flat workpiece was used for a trial study. Firstly, the new polishing tool which attached polishing cloth was developed. Then optimum polishing condition was investigated by using design of experiments method with developed tool. Finally, reflectance of workpiece which was polished by using optimum condition was measured and evaluated.

2. POLISHING METHOD FOR ALUMINUM

2.1. DEVELOPMENT OF THE POLISHING TOOL AND EXPERIMENTAL SETUP

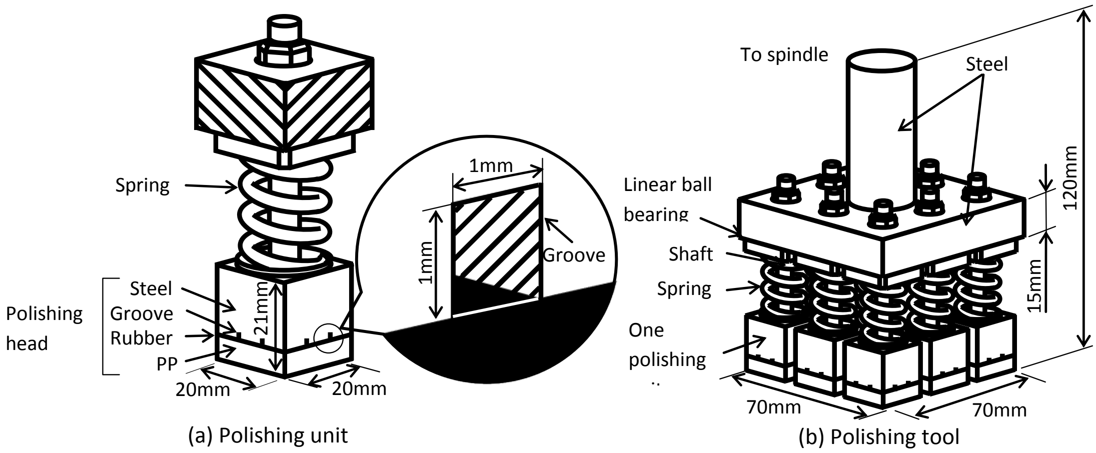


Fig. 1. Schematic view of the conventional polishing system

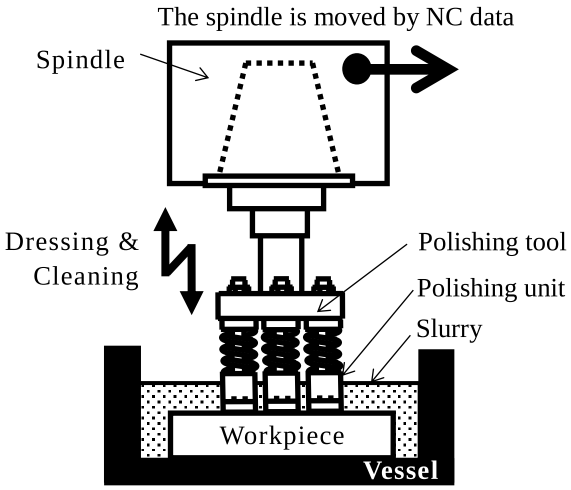


Fig. 2. Schematic view of the polishing process

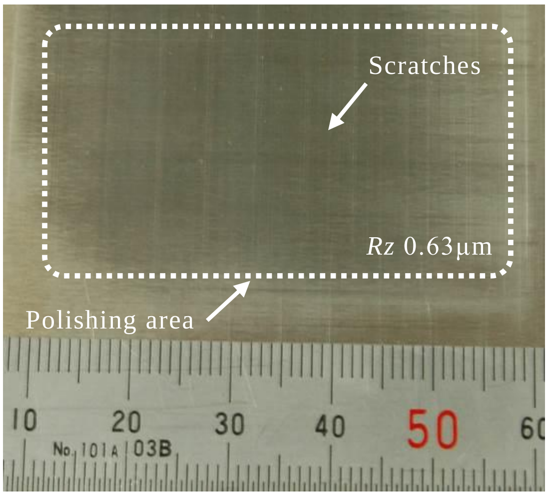


Fig. 3. Photograph of after polishing by using conventional method shown in Fig. 2

Fig. 1 shows a schematic view of a developed polishing tool in previous study [7]. This polishing tool consists of some polishing unit, and it can provide uniform pressure without chatter vibration. This polishing tool is attached to spindle of CNC milling machine by using collet chuck. Then the polishing tool moves by CNC control without spindle rotation as shown in Fig. 2. Workpiece is clamped in vessel which is filled with slurry mixing diamond grain and PEO (Poly-ethylene-oxide). This slurry's composition is shown in Table1. Slurry becomes non-Newtonian fluid by including PEO. As a result, diamond grain distribution in slurry becomes uniform for many hours. Furthermore, the Weissenberg effect is added to lapping slurry. Therefore, polishing unit attracts lapping slurry to polishing region efficiently [12]. When the polishing head contacts with workpiece, it catches diamond grain floating in slurry and moves holding diamond grain. Then diamond grain scratches workpiece with uniform depth and the surface of workpiece becomes mirror-like surface. After moving, polishing tool intermittently moves up and down. Due to this movement, chips existing between polishing head and workpiece are removed and new diamond grains are caught. Although this polishing system was applied to aluminum (A5052-H34), surface of aluminum was not sufficiently improved as shown in Fig. 3.

Therefore, in this research, a new polishing system was developed as shown in Fig. 4. The polishing cloth was fixed to base polishing tool using double-stick tape and banding band. Role of polishing cloth is not only holding diamond grains but also to collect chips. Although this theory is similar to buffing, differences between buffing and our developed polishing system are to control polishing pressure and to control behaviour of tool by stiffness of base polishing tool. Although this polishing system was used on several experimental conditions, surface roughness of workpiece was not efficiently improved. From preliminary experiment in this research, it was clarified that surface roughness of aluminum was efficiently improved by heating workpiece. Therefore, heater was installed on the slide table of NC transfer machine. Here, small and high speed spindle (Maximum rotation speed is 15000min^{-1}) was used as part of polishing tool. And polishing pressure was controlled by adjusting weight of spindle unit with a spring which is connecting spindle and housing flame.

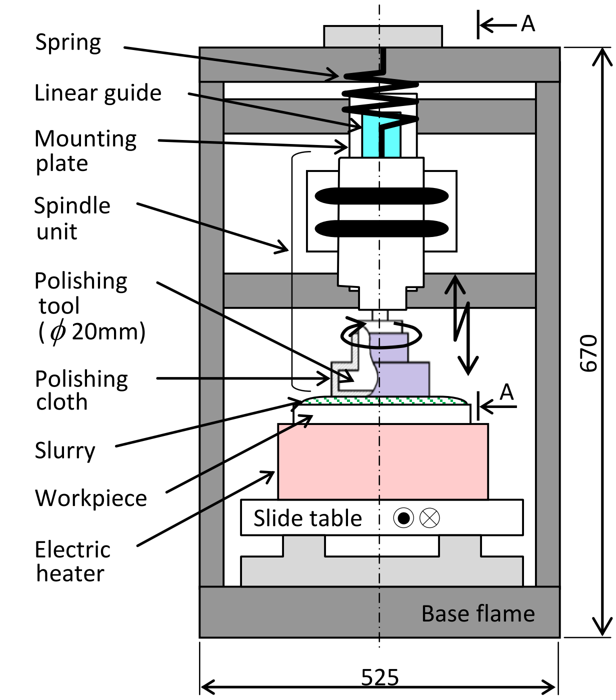


Fig. 4. Schematic view of new polishing system

Table 1. Polishing conditiofor preliminary experiment

Slurry		Base fluid	Water
		Diamond grain	Mesh size: #5000
		Ratio of diamond grain	2 wt% (wt% means the ratio by weight of solvent.)
		Ratio of PEO	2 wt%
Polishing condition		Rotation speed	15000 min^{-1}
		Average polishing pressure	60～90 kPa
		Feed speed	1000 mm/min
		Polishing length	30 mm
		Tilting angle of tool	0~9.8°
		Applied cycle of slurry (Applied amount)	Every 1 min. (approx. 2g)
	Workpiece	Material	Aluminum (A5052-H34)
		Length × Width × Thickness	125 mm×125 mm×2 mm
		Surface roughness	*Rz* 1.0 µm
		Heating temp.	23~90°C
	Polishing cloth ( )=Number of kinds		Composite (22)
			Rayon (16)
			Cotton (5)
			Sponge (2)
			Felt (3)

Average pressure: 60kPa / Tilting angele: 6.5°/ Heating temp.: 70°C

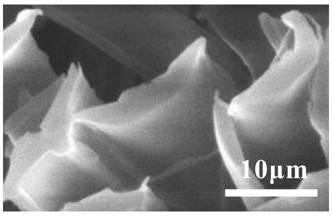
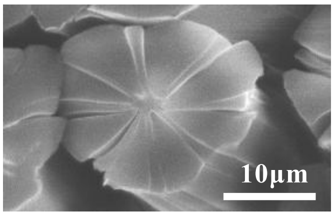
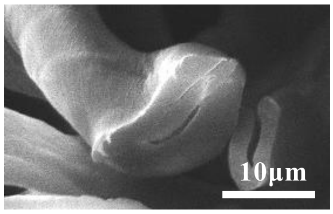
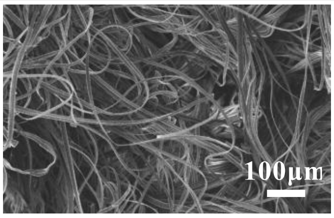
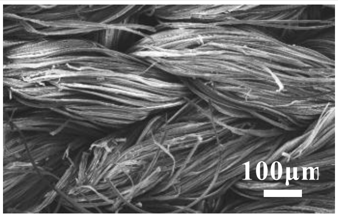
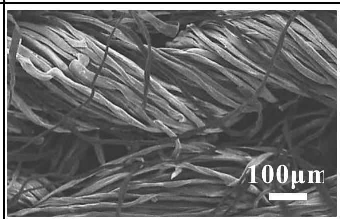
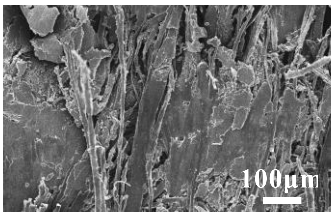
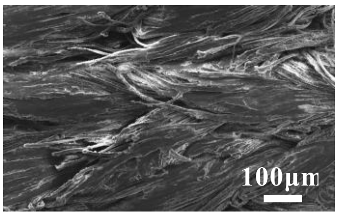
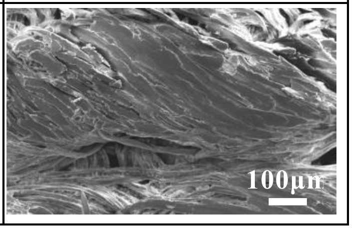
Kind of fiber	Splittable (PP and PET)	Splittable (Polyester and Nylon)	Cotton
Surface roughness *Rz* µm	0.15	0.15	0.21
Cross section			
Surface state before polishing			
Surface state after polishing			

Fig. 5. SEM photograph of several types of polishing clothes

Required features for polishing cloth are (1) to hold diamond grain and create scratches on workpiece (2) do not tear during polishing, (3) softness for pressing diamond grain to workpiece with uniform and minimal depth, (4) collect chips to prevent workpiece from generating unexpected scratches, (5) collect generated oxide during polishing to prevent oxide from adhering to workpiece. Therefore, several types of clothes were investigated according to Table1. Tilting angle of tool and heating temperature were set to 6.5° and 70°C respectively. And these effects will be discussed below. Evaluation result for some polishing clothes is shown in Fig.5. Surface roughness was measured along NC feed direction by using laser microscope (KEYENCE VF-7500: Standard length is 129μm, cut off is none, and resolution is 0.01μm.). From this result, it is confirmed that when polishing cloth using splittable fiber which consists of polypropylene (PP) and polyethylene terephthalate (PET) is used, most fine surface roughness was obtained. Splittable fibr is one of kind of composite fiber, and it is usually used as cleaning wiper and polishing cloth for hard disk [13]. Features of splittable fiber are (1) as it has sharp edge like a wedge, it can easily remove dust and oil spot. (2) diameter is so small that it has large surface area. Therefore, many foreign objects such as oxide and chips can adhere to splittable fiber. Actually, this polishing cloth wiped up the generated black dust during polishing. After that, surface roughness was gradually improved. In addition, this cloth did not tear after polishing. On the other hand, as cotton has circular cross-section, chips and oxide were not removed efficiently and surface roughness did not improve sufficiently. Therefore, the cloth used splittable fiber which consists of PP and PET (Manufactured by Daiwabo Polytec Co.,ltd) was used in following experiments.

2.2. CONSIDERATION ABOUT THE EFFECT OF TILTING MOUNTING PLATE FOR SPINDLE UNIT

Nexd linear guide was slightly tilted toward NC feed direction. Here, the effect between tilting angle of mounting plate and surface roughness is shown in Fig. 6. Polishing condition is followed on Table1.

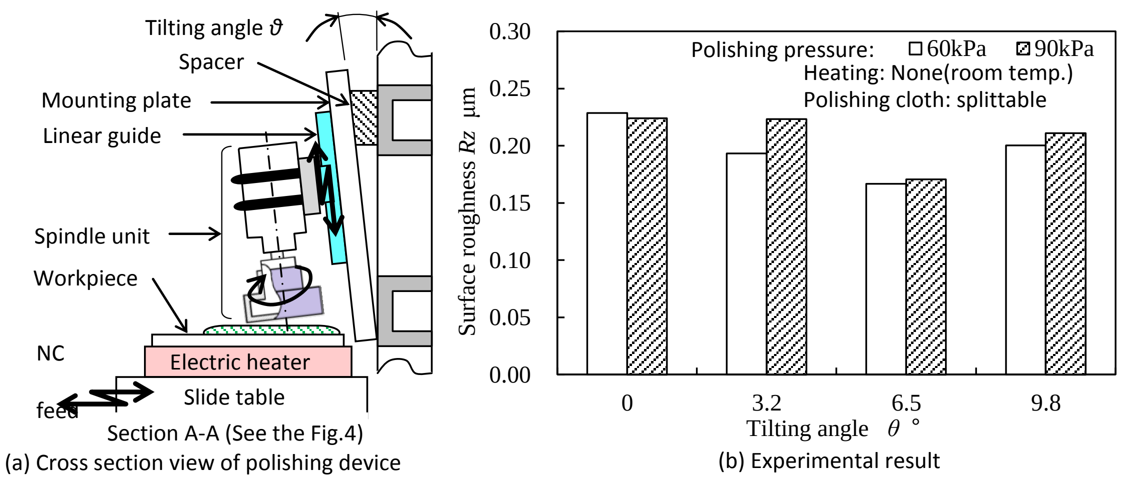


Fig. 6. Relationship between surface roughness and slant angle of base plate

Surface roughness was improved in proportion to increase of tilting angle up to 6.5°. In case of 0°, as circumferential velocity near center of tool is almost 0 m/s, polishing condition difference occurs in polishing area. Therefore, it is considered that surface roughness becomes non-uniform and worse. This trend was improved by tilting tool. In addition, difficulty of discharging chip near to the center of tool is a cause of this trend. On the other hand, even though average polishing pressure is same on each tilting angle, as contact area was small in case of 9.8°, polishing cloth was clogged locally with chips and damaged. So it is considered that surface roughness did not improve in case of 9.8°. Although polishing width is reduced to 7mm by tilting mounting plate, tilting angle of mounting plate was set as 6.5° in following experiments to improve surface roughness efficiently.

2.3. CONSIDERATION ABOUT THE EFFECT OF HEATING WORKPIECE

Next, it is confirmed the necessity of heating for aluminum. Relationship between heating temperature of workpiece and surface roughness is shown in Fig. 7. Experimental condition is same as Table1. As temperature of workpiece was raised up to 70°C, surface roughness was improved. When heating temperature was 23°C, chips almost did not adhere to polishing cloth. And it is confirmed that chips were easily adhered to polishing cloth by heating workpiece and surface roughness was improved since chips between polishing cloth and workpiece did not almost exist. When heating temperature is near 100°C, evaporation rate becomes faster and it is difficult to keep optimum slurry composition. And, since high heating temperature damages to polishing cloth, heating temperature is set as 70°C in following experiments. When heating temperature is 70°C, finished surface was not frosted.

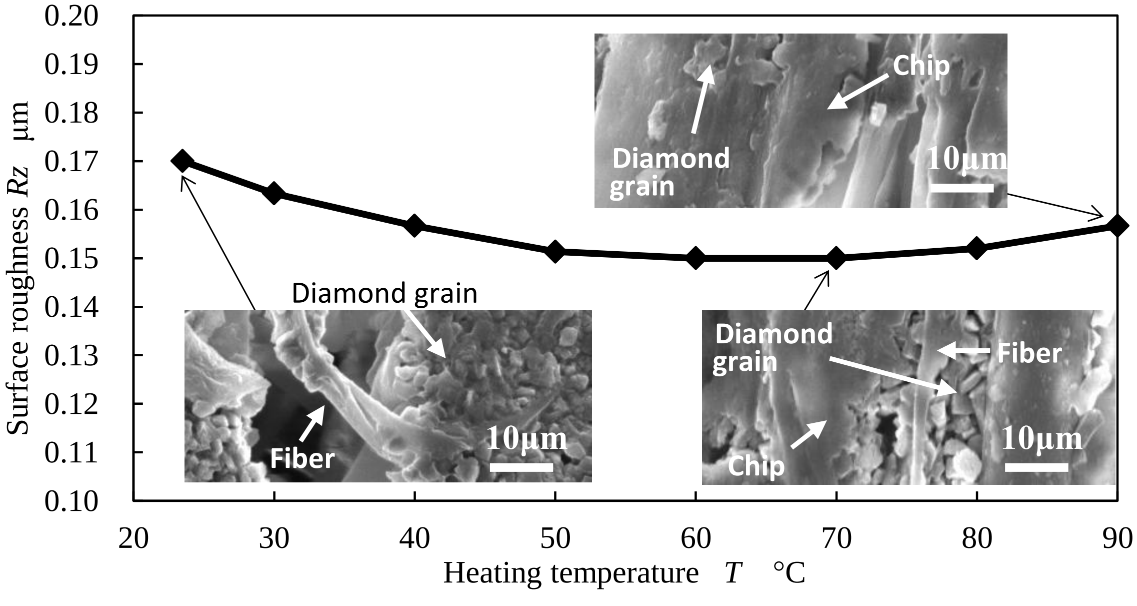


Fig. 7. Relationship between surface roughness and heating temperature of workpiece

2.4. CONSIDERATION OF OPTIMUM POLISHING CONDITION USING DESIGN OF EXPERIMENTS METHOD

Here, design of experiments method was used to clarify the optimum polishing condition for aluminum. High robustness is added to optimum condition by using this method. Control factors are rotation speed of spindle, feed speed and average polishing pressure. Noise factor is measurement location, which is measured at 5 locations. And output is surface roughness, which is measured along NC feed direction. As the first step, each level of control factor are set to 3 types, which are settable maximum, minimum and average value respectively. From this result, control factors are set as shown in Table 2 as the second step.

Experimental condition is also shown in Table 2. And L9 orthogonal array is used on experiments shown as Table 3. By using this array, number of experiments is reduced. This is one of typical features of design of experiments method. Required function is to obtain the smallest surface roughness possible for the investigated range.

Here, we must calculate SN ratio and sensitivity to clarify the effects of each control factor. SN ratio and sensitivity are calculated by using equation(1) and (2) respectively.

$$SN\ ratio = 10\log(m^2/\sigma^2) \tag{1}$$

$$Sensitivity = 10\log m^2 \tag{2}$$

Table 2. Experimental conditions for optimum condition

Control factor		Level 1	Level 2	Level 3
Rotation speed min^{-1}		10000	12500	15000
Feed speed mm/min.		1000	1500	2000
Average pressure kPa		50	60	70
Polishing cloth		Splittable (PP and PET)		
Polishing area		W:7mm × L:30mm		
Workpiece	Material	A5052-H34 (*Rz* 1.0 μm)		
	Heating temp. °C	70		
Slurry	Base fluid	Water		
	Diamond grain	Mesh size : #5000 (2wt%)		
	Ratio of PEO	2wt%		
	Applied cycle	Every 1min.		

Table 3. L9 ortogonal array for evaluating optimum condition

No.	Rotation speed	Feed speed	Polishing pressure
1	10000	1000	50
2	10000	1500	60
3	10000	2000	70
4	12500	1000	60
5	12500	1500	70
6	12500	2000	50
7	15000	1000	70
8	15000	1500	50
9	15000	2000	60

Here, m is average value of measured surface roughness and σ is standard deviation. From equation(1), it is confirmed that large SN ratio means small variation. From equation(2), small sensitivity means to obtain small surface roughness. It is confirmed that when we select the level with large SN ratio and small sensitivity, we can obtain optimum condition with high robustness from equation (1) and (2), which is to obtain small surface roughness with small variation.

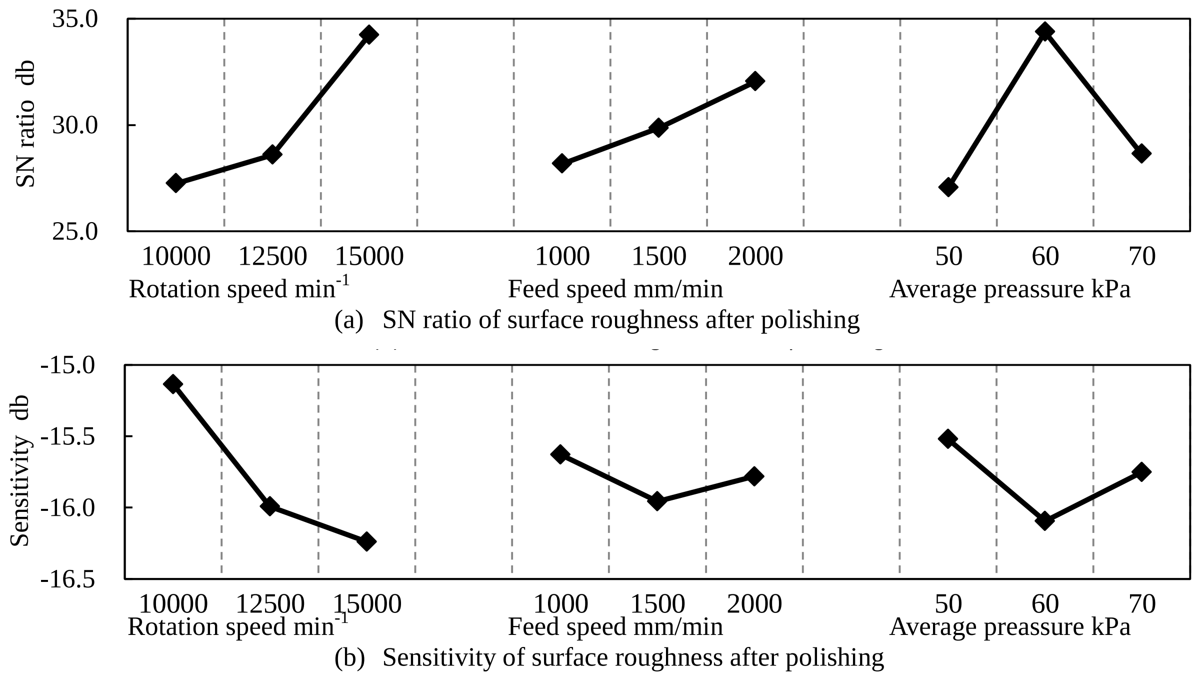


Fig. 8. Graphs of factorial effects

Fig. 8 shows the graphs of factorial effects for SN ratio and sensitivity. As previously noted, final objective is to obtain small surface roughness with high solar reflectance. Therefore, optimum rotation speed, feed speed and average pressure are selected 15000min^{-1}, 1500mm/min and 60kPa respectively in priority to sensitivity. This optimum polishing condition as shown in Table 4 was used on subsequent experiments.

Table 4. Optimum polishing condition

Rotation speed min^{-1}		15000
Feed speed mm/min		1500
Average pressure kPa		60
Polishing cloth		Splittable (PP and PET)
Heating temp. °C		70
Slurry	Base	Water
	Diamond grain	Mesh size : #5000 (2wt%)
	PEO	2wt%

2.5. CONSIDERATION OF POLISHING EFFICIENCY

Fig. 9 shows the relationship between surface roughness and exchange cycle of polishing cloth. Polishing cloth was exchanged every 3 minutes and every 6 minutes to compare each exchange cycle. Although exchange cycle of polishing cloth was different, surface roughness change curve and final surface roughness were almost the same. Here, experiment was performed with cloth used for 6 minutes in evaluation for exchange cycle. Then almost the same surface roughness in case of exchange cycle for 3 and 6 minutes was obtained as shown Fig.9. Therefore, it is considered that surface roughness reached to limit surface roughness regardless exchange cycle of polishing cloth. Hence, polishing cloth was used until surface roughness reaches to limit surface roughness or polishing cloth is torn.

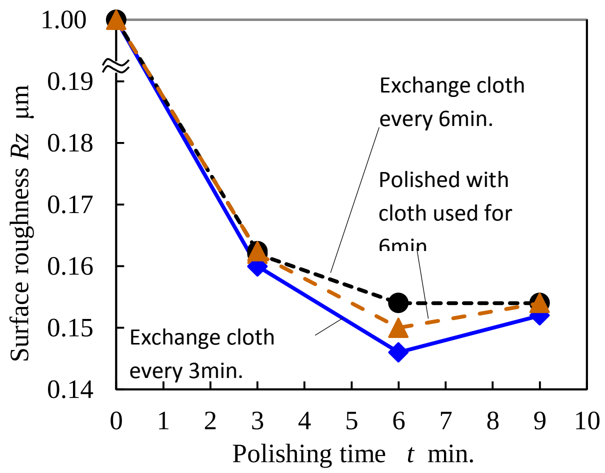


Fig. 9. Relationship between surface roughness and exchange cycle of polishing cloth

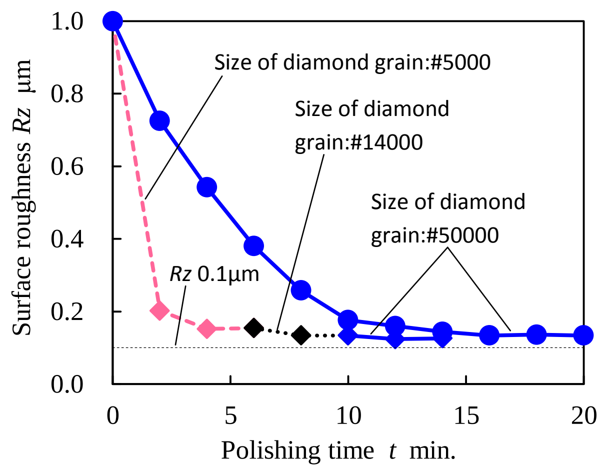


Fig. 10. Relationship between surface roughness and polishing time

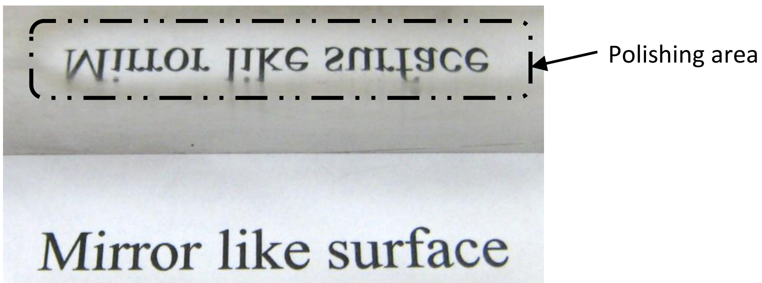


Fig. 11. Photograph of workpiece after polishing with optimum polishing condition

Fig. 10 shows the relationship between surface roughness and polishing time with optimum polishing condition. Here, the combination of diamond grain size #5000, #14000 and #50000, which was obtained fine surface roughness in a short time on preliminary experiment, and the case of using only #50000 were tried to compare the productivity. In case of the combination of the former, slurry including #14000 and #50000 diamond grain respectively were made with same composition as Table 4 and diamond grain size was changed after reached each limit surface roughness. And when slurry was used only #50000, polishing cloth was exchanged only 1 time at 14minutes since polishing cloth was torn. Mirror-like surface, in other words Rz is less than or equal to 0.1μm, was not obtained, then maximum height Rz was 0.13μm. Fig.11 shows a photograph of workpiece after polishing. However, it was clarified that polishing time was reduced up to a quarter of using only #50000 by changing diamond grain size. Therefore, it is considered that this polishing system is effective for aluminum.

3. EVALUATION OF SOLAR REFLECTANCE FOR CONCENTRATOR OF CPV

One of most important factor for concentrator of CPV is not surface roughness but also high solar reflectance. Fig. 12 shows a schematic view of CPV. Incident ray is focused by concentrator and irradiated to solar cell for CPV. Here, conversion efficiency of CPV is calculated by equation (3).

$$\eta_{CPV} = \eta_{con} \cdot \eta_{cell} \cdot \eta_{opt} \tag{3}$$

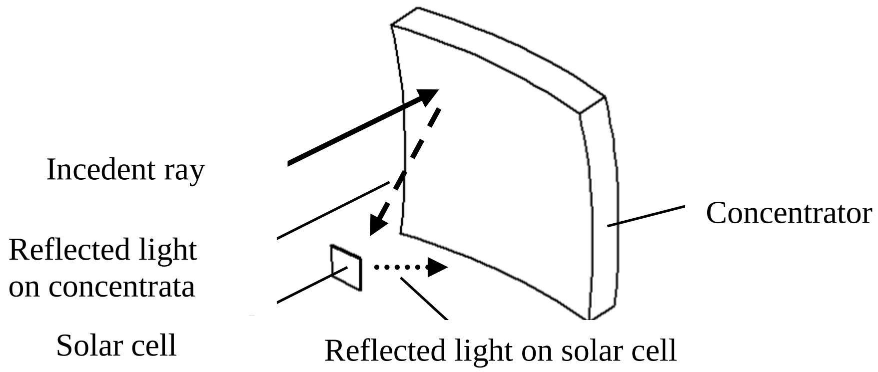


Fig. 12. Schematic view of CPV

Where, η_{CPV} is conversion efficiency of CPV, η_{con} is solar reflectance of concentrator, η_{cell} is conversion efficiency of solar cell and η_{opt} is absorption efficiency of solar cell. From this equation, it is clearly influenced by solar reflectance of concentrator. Therefore, spectral reflectance of specimen which is polished with optimum polishing condition was measured to calculate solar reflectance in this section. Spectral reflectance was measured by spectrophotometer (JASCO Corporation:V-670), which can measure spectral reflectance from ultraviolet to near-infrared wavelength. In this study, spectral reflectance corresponding to each wavelength from 300nm to 2000nm was measured with changing wavelength each 1nm. That wavelength range is almost covered the AM1.5D spectrum. AM1.5D is generally used as average sunlight spectrum on the ground of latitude near Japan. Therefore, AM1.5D was used as base light in this section. And incidence and reflection angle are set to 5° respectively. Here, weighted reflectance is expressed by equation (4).

$$R = \int_{300}^{2000} I(\lambda)\rho(\lambda)d\lambda \Big/ \int_{300}^{2000} I(\lambda)d\lambda \tag{4}$$

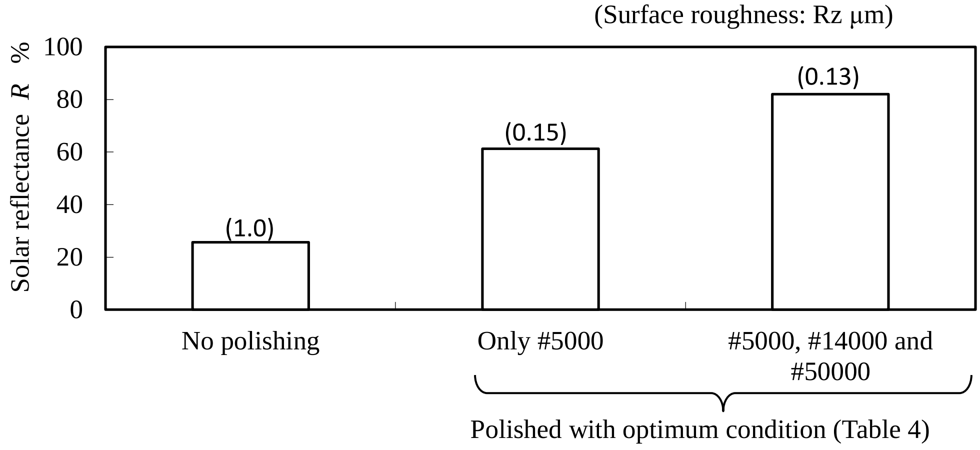


Fig. 13. Measurement result of reflectance by spectrophotometer

Where, R is solar reflectance weighted by base light , I(λ) is spectrum of base light and ρ(λ) is spectral reflectance, which is average value calculated with measuring result at 3 locations. Here, measuring area of spectral reflectance is 5mm×10mm.

Fig. 13 shows the calculated results of solar reflectance. In this figure, specimen without polishing, polished specimen used only #5000 diamond grain and polished specimen with optimum condition are also shown to compare the influence of polishing. Solar reflectance of polished specimen with optimum condition was 82%. To obtain more high reflectance, it needs to improve surface roughness further. And form accuracy and polishing for spherical surface must be evaluated as further studies.

4. CONCLUSION

From the above results, it can be concluded that; (1) New polishing tool which attached polishing cloth was developed. Optimum polishing cloth for aluminum is cloth using splittable fiber which consists of PP and PET. (2) By tilting spindle unit and heating workpiece on developed polishing system, surface roughness of aluminum was improved up to Rz 0.13μm. But mirror like surface could not obtain. (3) Optimum polishing condition for developed new tool was revealed. (4) Fine polishing surface which has 82% solar reflectance was obtained with proposed optimum polishing condition.

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