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GRINDING CHARACTERISTICS OF POLYCRYSTALLINE SILICON

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Abstract. In this study, up and down surface plunge grinding tests have been carried out in polycrystalline silicon workpieces. In the tests resin bonded diamond wheels of different abrasive grain size were used under varying conditions of cutting depth and workpiece velocity. Experimental results show that the specific grinding energy decreases as the maximum undeformed chip thickness increases regardless of abrasive grain sizes and modes of grinding. The surface roughness with larger grain size is greater than that with smaller one. In the case of 120 mesh grain, the magnitudes of surface roughness for up grinding are distinctly greater than those for down grinding.

1. INTRODUCTION

Presently polycrystalline silicon is widely used to construct solar cells because of its low production costs. However the energy conversion efficiency of solar cells based on polycrystalline silicon is lower than that of single crystalline ones [1].

To overcome this disadvantage, lots of efforts have been taken to grow polycrystalline silicon with highly oriented grains during directional solidification [2].

Once a polycrystalline silicon ingot is manufactured, it will be sawn into bricks of appropriate size. Then bricks are sawn again into very thin wafers which will be used as solar cell components. But before a brick is sawn into wafers, surfaces and corners of it should be ground to give smooth finish, which can reduce the possible subsurface damages and result in increased yield due to less wafer breakage during wire sawing [3].

In this study, the specific grinding energy and the surface roughness dependence on the maximum undeformed chip thickness of polycrystalline silicon have been investigated.

2. MAXIMUM UNDEFORMED CHIP THICKNESS

The maximum undeformed chip thickness in grinding process is the penetration depth of cutting point in the material being ground. Its magnitude depends upon the topography of the grinding wheel surface, the grinding geometry and the kinematics motions of wheel and workpiece which constitute the input conditions of grinding process.

A number of equations on the maximum undeformed chip thickness have been introduced. However, most of these contain an experimentally determined factor called the successive cutting point spacing [4]. It confines the practical use of these equations in the research of grinding process.

Recently Lee *et al.*, using the average grain model, derived an equation of the maximum undeformed chip thickness, h_{max} Eq. (1),

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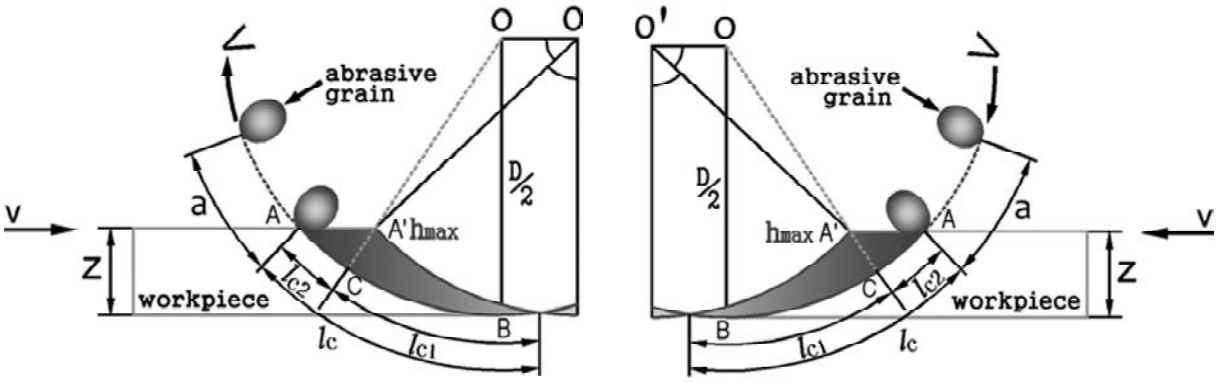

Fig. 1. Up grinding (a) and down grinding (b).

$$h_{max} = \left(\frac{1}{n\sqrt{d_g}} \frac{v}{V} \sqrt{\frac{Z}{D}} \right)^{2/3}, \quad (1)$$

where n is number of cutting points per unit area of the wheel surface, d_g is average diameter of abrasive grain, v is workpiece velocity, V is wheel peripheral velocity, Z is grinding depth of cut, and D is diameter of grinding wheel. In this equation, the maximum undeformed chip thickness can be estimated without using any experimentally obtained data [5].

Figs. 1a and 1b illustrate the up and down surface grinding respectively. In the figures the line segment A'C represents the maximum undeformed chip thickness, h_{max}.

3. SPECIFIC GRINDING ENERGY

For surface grinding, the force exerted by the workpiece against the wheel can be separated in tangential and normal components F_t and F_n. Fig. 2 illustrates the schematic of force measurement of surface grinding.

The grinding power, P can be written as in Eq. (2).

$$P = F_t V. \quad (2)$$

The specific energy, u defined as the energy required to remove the unit volume of material, and can be expressed as in Eq. (3),

$$u = \frac{F_t V}{b v Z}. \quad (3)$$

where b is grinding width.

4. EXPERIMENTS

Polycrystalline silicon was used as work material. Workpieces were prepared to 8 mm width and 70 mm long. The grinding input conditions are presented in Table 1.

5. RESULTS AND DISCUSSION

Figs. 3a-3d show the specific grinding energy, u dependence on the grinding depth of cut, Z. As shown in the figures, the specific energy, u decreases with increase of the grinding depth of cut. Figs. 4a-4d show the specific grinding energy, u dependence on the workpiece velocity, v. As shown

Table 1. Grinding input conditions.

Grinding machine	Horizontal spindle surface grinding machine (3.5 kW)
Grinding wheels	D120N125B, D325N125B
Wheel speed (rpm)	1750
Workpiece velocity (m/min)	5, 10, 15, 20
Depth of cut (μm)	10, 20, 30, 40
Grinding modes	Up and down grinding
Coolant	None

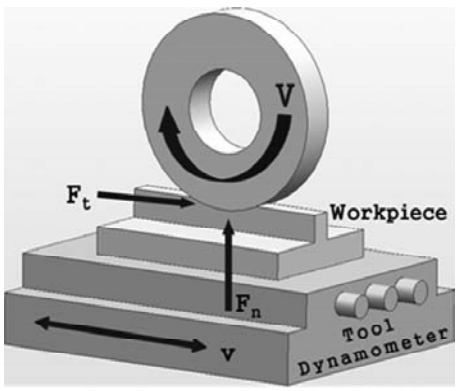

Fig. 2. Force measurement of surface grinding.

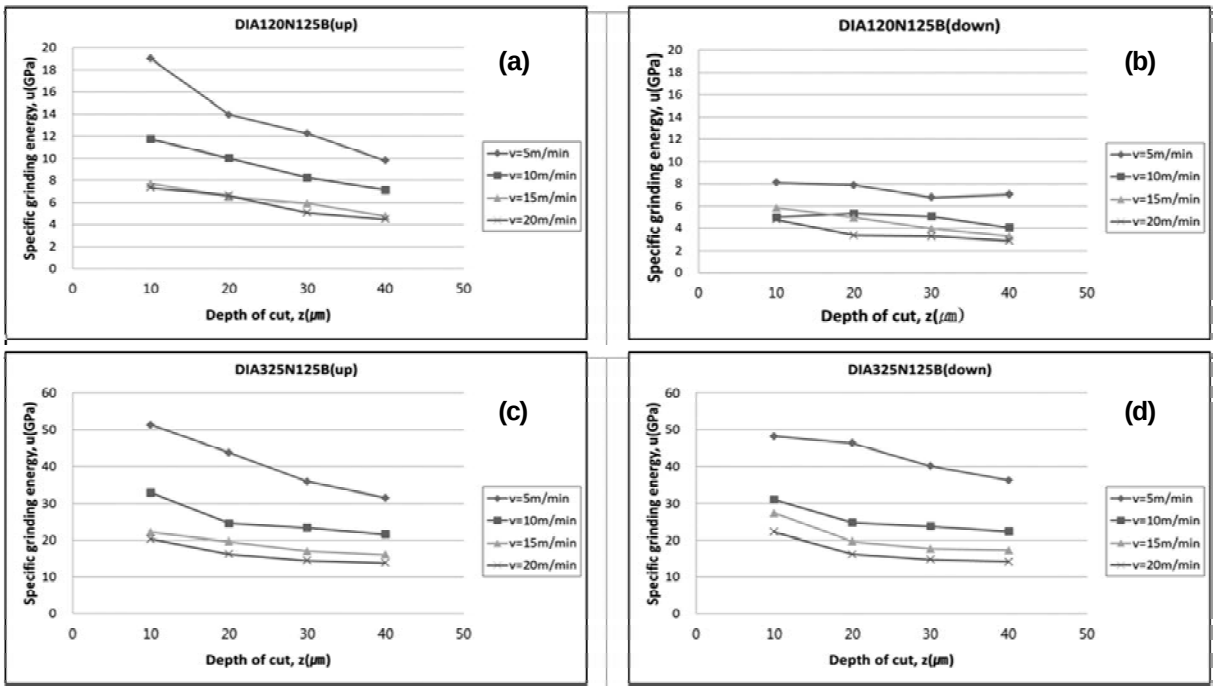

Fig. 3. Specific grinding energy, *u* vs. depth of cut, *Z*.

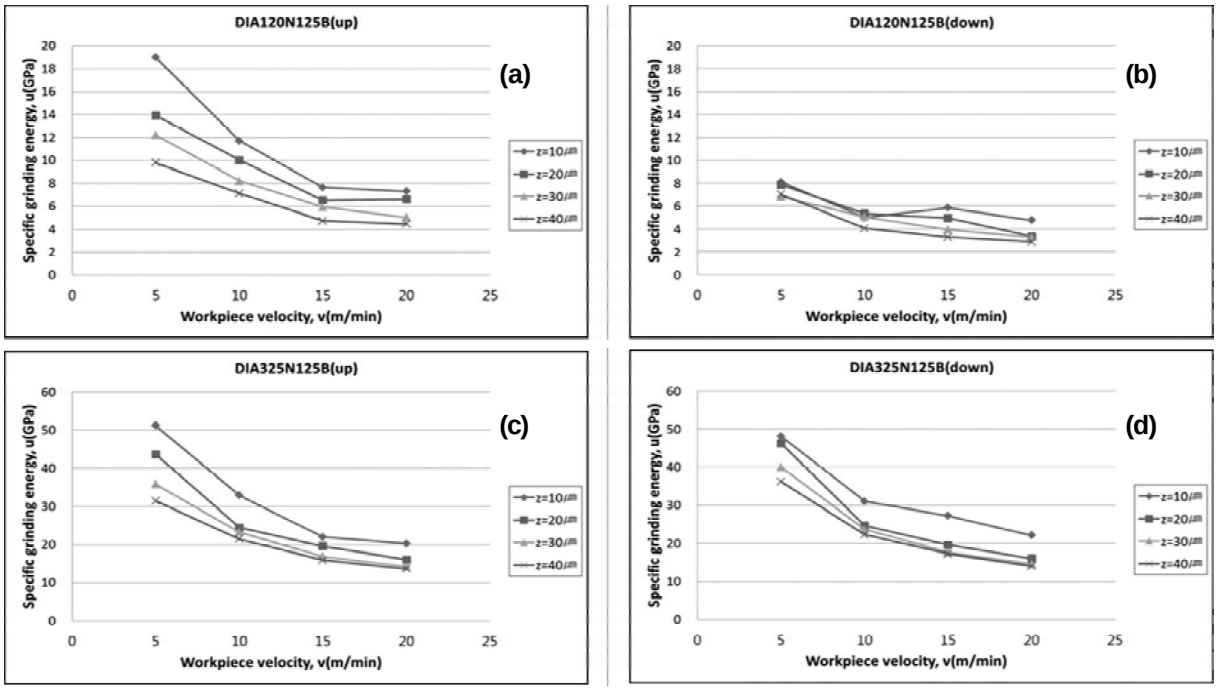

Fig. 4. Specific grinding energy, *u* vs. workpiece velocity, *v*.

in the figures, the specific energy, *u* again decreases with increase of the workpiece velocity, *v*.

These results are probably due to 'the size effect' in grinding operation [6,7].

Fig. 5 shows two groups of the specific grinding energy, u versus the maximum undeformed chip thickness, h_{max} for up and down grinding modes using 120 and 325 mesh grain wheels. The specific grinding energy, u decreases with increase of the maximum undeformed chip thickness regardless of grain sizes and modes of grinding.

The specific energies with 325 mesh wheel are far greater than those with 120 mesh one, however the magnitudes of the maximum undeformed chip thickness with 325 mesh wheel are far less than those of 120 mesh one.

Fig. 6 shows the center line average roughness, R_a measured transverse to the grinding direction

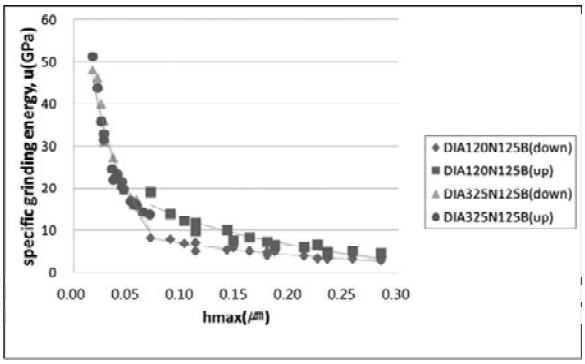

Fig. 5. Specific grinding energy, *u* dependence on maximum undeformed chip thickness, h_{max}.

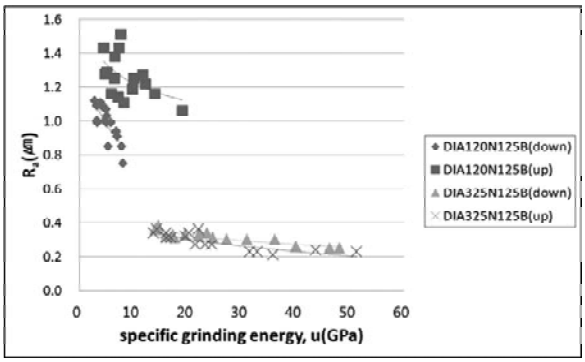

Fig. 6. Surface roughness, R_a dependence on maximum undeformed chip thickness, h_{max}.

versus the maximum undeformed chip thickness, h_{max} for up and down grindings using 120 and 325 mesh grain wheels.

As shown in the figure the values of surface roughness with 120 mesh wheel are appreciably greater than those with 325 one. In case with 120 grain wheel the values of roughness for up grinding are distinctly greater than those for down grinding.

6. CONCLUSIONS

From the results of surface grinding experiments of polycrystalline silicon it can be concluded as follows:
(1) Much more energy was consumed with smaller grain size grinding wheel than larger one under the identical grinding conditions of cutting depth and workpiece velocity.
(2) The specific grinding energy decreases as the maximum undeformed chip thickness increases regardless of grain sizes and grinding modes.
(3) The values of surface roughness obtained with smaller grain size are far less than those with larger one.
(4) The values of surface roughness obtained during up grinding are greater than those of down grinding with 120 mesh grain wheel.

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