In-process control of ground surface quality related to thermal distribution between diamond grain and workpiece

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Abstract. Smooth surface grinding depends on material micro-removal by diamond grain, but thermal damage is unavoidable. Hence, the thermal distribution between diamond grain and workpiece is adjusted to improve the ground surface quality by changing grain top area. Firstly, the grain top area was determined through thermal transmission balance on workpiece surface. Secondly, the mechanical dressing was utilized to remove the diamond grain top. Finally, the dry grinding of D-star die steel was conducted to analyze the correlation between surface quality and grain top area. The results show that the mechanical dressing increases the grain top area by about 2 times to reduce the workpiece grinding temperature. At the thermal transmission balance on workpiece surface, the thermal deformation is suppressed to decrease the ground surface roughness by 72.4% for smooth grinding.

1. Introduction

Metal materials such as die steel[1], titanium alloy[2] and hard alloy are main materials for precision instruments and micro-electronic components. Efficient production of these components with free pollution is the ultimate goal for precision machining. Therefore, how to use pollution-free dry grinding to generate smooth ground surface is a problem that needs to be solved.

The topography of diamond grain is an important factor that affecting the ground surface quality[3]. However, the distribution of diamond grain on the wheel circumferential surface is random[4]. Therefore, the laser dressing[5] and electro-discharge dressing[6] were proposed to control the grain topography and improve the grain uniformity of wheel circumferential surface. In these dressing methods, the diamond grain will be graphitization due to applied thermal, resulting in micro removal of the diamond grain. Meanwhile, burning and thermal deformation will occur on the workpiece surface because of thermal accumulation[7]. Therefore, it is worth investigating the control of thermal transmission and distribution between the diamond grain and workpiece.

In this paper, the thermal distribution between the workpiece and diamond grain during grinding process was studied to improve the grinding quality. Firstly, according to grinding parameters and material characteristics, the desired top area of grain was calculated. Secondly, the grain was dressed by controlling thermal distribution. Finally, this method was applied to dry-grinding D-Star die steel, which
successfully achieved reduction of thermal deformation on the ground surface by thermal distribution control.

2. Methodology

Fig. 1 demonstrates the diamond grain-material contact in the grinding experiment. A wheel rotating at a rotational speed $N$ moves along direction of X-axis and depth of $a_p$ at a feed rate $v_f$. During the grinding process, the cutting interface area between diamond grain and workpiece is equal to grain top area $s_d$.

The total thermal generated by the cutting interface which determined by the wheel rotational speed $N$, cutting depth $a_p$ and feed rate $v_f$. The thermal is transmission in both directions of diamond grain and workpiece simultaneously (diamond thermal $Q_d$ and workpiece thermal $Q_w$) and the thermal distribution ratio $Q_d / Q_w$ is positively correlated with area $s_d$.

Fig. 1. Thermal transmission in grinding

Fig. 2 shows effect of area $s_d$ on thermal distribution and temperature change. $Q_w$ increases and tend to be stable with the area $s_d$ increased, and workpiece surface temperature decreases accordingly. $Q_d$ decreases and tend to be stable with the area $s_d$ increased, and diamond temperature decreases accordingly. Due to the thermal distribution ratio increase, the decreasing trend of diamond grain temperature is slow.

$T_{gra}$ and $T_{smo}$ is minimum and maximum temperature of the grain graphitization removal and workpiece without thermal deformation, respectively. $S_{gra}$ and $S_{smo}$ are corresponding grain top areas, where $S_{gra}$ will move to the right of the coordinate axis as the total thermal increases. Hence, according to the processing requirements of the workpiece, the required grain top area $s_{smo}$ without grinding burn could be calculated. And then the wheel rotational speed $N$, cutting depth $a_p$ and feed rate $v_f$ can be controlled to make $S_{gra}$ greater than $S_{smo}$. Finally, grain top area is dressed to $S_{gra}$ by thermal distribution to suppressing thermal deformation of the ground surface.

Fig. 2. Effect of area $s_d$ on thermal distribution and temperature change:
(a) thermal distribution, (b) temperature change
3. Experiment and measurement

Fig. 3a shows grain dressing by iron dresser. In this experiment, dressing duration of 8h was taken dresser to modify the grain top area. Fig. 3b shows dry grinding with dressed grinding wheel. In this experiment, difficult-to-cut material of D-star die steel was used to identify the smooth surface quality. Experimental conditions of dressed and dry grinding are shown in Table 1. Among them, the dressing parameters are obtained by thermal distribution calculation.

![Fig. 3. Experiments on diamond grinding wheel: (a) grain dressing by iron dresser, (b) dry grinding](image)

### Table 1. Experimental conditions of dressing and dry grinding

| Experiment          | Dressing                      | Dry grinding                  |
|---------------------|-------------------------------|-------------------------------|
| Grinder             | Smart-B818                    | Smart-B818                    |
| Grinding wheel      | #46 (Bronze bond), Diameter D=150 mm, Concentration 100% | #46 (Bronze bond), Diameter D=150 mm, Concentration 100% |
| Dresser/workpiece   | Iron                          | D-star                        |
| Grinding manner     | Z axial-feed                  | Z axial-feed                  |
| Dressing/Grinding   | $N=2400$ rpm, $a_p=8 \mu$m, $v_f=500$ mm/min, $\Delta z=1$ mm | $N=2400$ rpm, $a_p=6 \mu$m, $v_f=50$ mm/min, $\Delta z=15$ mm |
| Coolant             | Air medium                    | Air medium                    |

In addition, grain topography was investigated through scanning electron microscope (SEM, FEI Quanta 200). Surface roughness of D-star were measured by contour meter (TALYSURF CLI 1000) and electron microscope (SEM, Zeiss Merlin).

4. Results and discussion

Fig. 4 shows grain topography before dressing and after dressing, respectively. The results show that the dressing parameters calculated by thermal distribution and the iron dresser can effectively dressed the grain top area to the target value, and the grain top area increases by 8600 $\mu$m² to 23400 $\mu$m². In addition, the dressed faces became smooth along the cutting direction.

![Fig. 4. Grain topography: (a) before dressing, (b) after dressing](image)

Fig. 5 shows surface roughness $Ra$ of difficult-to-cut material D-star die steel. Surface roughness $Ra$ is mean of measured vertical profiles perpendicular cutting direction. Compared with ordinary grinding, the surface roughness $Ra$ of D-star die steel from 1235 nm decreases 72.4%, which reached 340 nm.
Fig. 5. The surface profile of D-star die steel:
(a) thermal transmission balance control grinding, (b) ordinary grinding

Fig. 6 shows the grinding surface morphology of the workpiece. It is clear that control thermal distribution grinding can effectively avoid thermal deformation caused by heat accumulation and obtain better surface grinding quality.

![Surface profile of D-star die steel](image1)

![Grinding surface photograph](image2)

Fig. 6. Grinding surface photograph: (a) Thermal distribution control grinding, (b) ordinary grinding

### 5. Conclusions

The thermal distribution between diamond and workpiece depends on grain top area in grinding process. For material cutting, the thermal transmission balance on workpiece surface suppresses the thermal deformation to improve ground surface quality. For diamond grain dressing, the thermal transmission balance on diamond cutting interface dominates the diamond thermochemical removal to control the grain top area.

In D-star die steel grinding, the dressed grain top area increases by about 2 times to reduce the workpiece grinding temperature due to outstanding diamond thermal conductivity. It may decrease the ground surface roughness from 1235 nm to 340 nm, up to 72.4%. As a result, smooth grinding of difficult-to-cut metallic materials can be achieved by adjusting the thermal distribution in relation to grain top area.
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