Experimental Investigation on Face Grinding of 2024Al/SiCp with Electroplated Diamond Wheel

Wang Shaolei, Shi Shuzheng, Wang Jiuqiang, Li Xin, Wang Zhanying, Zhu Chunhua

School of Machine, Hebei University of Architecture, Zhang Jiakou, HeBei, 07500, China
2683458312@qq.com

Abstract. SiCw / 2024Al composite has excellent physical and chemical properties, such as high specific strength, good wear resistance, low coefficient of thermal expansion, etc. It has been widely used in the development of modern science and technology. An experimental research on face grinding of SiC particle-reinforced aluminium matrix composite 2024Al/SiCp with electroplated diamond grinding wheel was carried out. The effects of different grinding parameters on the surface morphology, grinding force and grinding quality of workpiece are analyzed. The results show that high quality ground surface can be achieved by using this technology; the residual stress on machined surface is compressive stress; grinding parameters have little effects on tangential and normal grinding forces, but have stronger effect on axial grinding force than that in other two directions, and the axial grinding force increased notably as the increasing of grinding depth. Keywords: Aluminum matrix composite; grinding; Processing characteristics; Experiment

1. Introduction
As a kind of important new material, aluminum matrix composite has many advantages, such as high temperature resistance, high specific strength, high specific mode, small coefficient of thermal expansion, good wear resistance and chemical stability. It has been widely used in aerospace and other high-tech fields. [1] But the excellent physical and chemical characteristics that make them difficult to machine. When cutting tools with ordinary materials, the tool wear is serious and it is difficult to obtain high-quality surface. [2]

PCD tools are usually used to process SiC particle reinforced aluminum matrix materials. However, PCD tools have high manufacturing cost and high processing cost. [2-3] In view of this, EDM, laser processing and other special processing methods have been tried to be applied to the processing of this kind of material, but the results are general, and there are generally disadvantages of low processing efficiency and poor workpiece processing quality. [4]

Grinding is a common processing method for machining hard and hard materials with high hardness. It has the advantages of high efficiency, high processing quality and low cost. Therefore, it is of great theoretical and practical significance to study the grinding characteristics of aluminum matrix composites for forming an efficient, high-quality and low-cost processing method and promoting the popularization and application of particle reinforced aluminum matrix composites. [5-7]

The study of grinding characteristics mainly refers to the study of the influence of different grinding parameters on the grinding quality of workpiece. By changing different grit size of plated diamond grinding wheel, changing grinding wheel speed, feed speed, cutting depth and other parameters, the
corresponding surface quality and grinding force are measured, and the influence rule of processing parameters on surface quality is analyzed.

2. Experimental conditions and methods

Figure 1 shows the CNC grinding machine for machining, and the main parameters of electroplated diamond grinding wheel are shown in Table 1.

![Figure 1. Plane CNC grinding machine](image)

**Table 1. Main parameters of electroplated diamond grinding wheel**

| Ceramic bond | Diamond particle size |
|--------------|-----------------------|
| Mainly silica | 0.015mm-0.030mm |

Test materials (40% SiCp + 5% grpal) are aluminum matrix composites prepared by squeeze casting. The particle size of SiC reinforced particles is 15μm, and the physical and mechanical parameters are shown in Table 2. The processing parameters are shown in Table 3.

**Table 2. Physical parameters of test materials**

| Density g/cm³ | Yield strength/MPa | Tensile strength /MPa | Elongation rate /% | Volume fraction | Modulus of elasticity /GPa |
|---------------|---------------------|----------------------|-------------------|----------------|---------------------------|
| 2.87          | 420                 | 498                  | 6                 | 156            | 40%                       |

**Table 3. Processing parameters (under coolant)**

| Spindle speed (rpm) | Feed rate (m/min) | Grinding depth (mm) |
|---------------------|-------------------|---------------------|
| 3000                | 5                 | 0.002               |
| 4000                | 9                 | 0.003               |
| 5000                | 13                | 0.004               |
| 6000                | 17                | 0.005               |
| 7000                | 21                | 0.006               |

3. Experimental results and analysis

3.1. Micro morphology of grinding surface

After grinding, the surface morphology was observed by scanning electron microscopy (SEM), the residual stress was measured by X-ray diffraction, and the grinding force was measured by Kistler piezoelectric ceramic dynamometer (charge amplifier 0.8mm, measuring length 5mm).

Figure 2 shows the results of scanning electron microscope (SEM) observation on the surface morphology of the workpiece after grinding. Grinding process parameters: \( s = 6500 \text{rpm}, \ AP = 0.002 \text{mm}, \ f = 10 \text{m/min} \). Fig. 2 (a) shows the surface morphology of the workpiece with a magnification of 200 times. The surface is covered with wear marks along the feed direction of the
workpiece, and a large number of processing defect patches with different sizes are randomly scattered. This is a typical morphology characteristic of the reinforced SiC and the matrix.

![Figure 2. SEM image of machined surface](image)

As shown in Fig. 2 (a), the area full of wear marks is aluminum matrix material, which is formed by the surface of Al material of grinding wheel abrasive grain ploughing matrix. Further magnify and observe the grinding trace area, as shown in Fig. 2 (b), the grinding trace presents furrow shape, the bottom of the furrow is relatively smooth, and it turns outward and folds to both sides. It is due to the low hardness of aluminum based materials, the friction heat produced in the processing process makes the aluminum matrix softer, and the abrasive grains of grinding wheel cut into the matrix materials.[8-9] Al matrix is pushed to both sides by abrasive particles to form uplift plastic deformation. The grinding wheel and diamond grains plough the aluminum matrix material, and the aluminum matrix is pushed to both sides by the abrasive grains through plastic deformation to form a bulge with folds.

The processing defect patch is the contact part between SiC reinforced particles and aluminum based materials. As shown in Figure 2 (c), aluminum based materials are squeezed by high hardness SiC particles, resulting in pits and holes, as well as grooves with uneven width, depth and shape. It is due to the plastic deformation and the loosening and falling off of SiC particles. At the same time, under the action of abrasive wheel, SiC particles also have elastic deformation, breaking and falling off.

As the grinding process goes on, the interaction between the grinding wheel and the material surface causes the SiC particles to break, as shown in Figure 2 (d). Part of the brittle fracture grain SiC is brought out by the cutting edge of the grinding wheel and falls off, leaving a cavity. Microcracks appear in the hardened layer of Al matrix under the action of the interface force between particles and matrix.[10] It can be seen that the large stress concentration in the aluminum matrix and the interface between the two phases in the SiC particle aggregation area results in the debonding of the matrix and the particles, and the cracks are generated in the aluminum matrix and the interface between the particles and the matrix. With the connection of the cracks, the material is cut down and the non cut surface is formed.

3.2. The influence of grinding surface roughness

Roughness is an important parameter used to evaluate the surface integrity after machining. The continuity and uniformity of internal materials affect the surface integrity, making the surface roughness different after machining. As the material of particle reinforced aluminum matrix composite is not uniform, the grinding direction has a great influence on the roughness. The surface roughness is measured along the grinding direction and perpendicular to the grinding direction.

As shown in Figure 3, the effect of different grinding depth and spindle speed on the roughness is described. It is obvious that with the increase of spindle speed, the roughness of the processed workpiece shows a downward trend, but the greater the grinding depth is, the less obvious the decrease of the roughness is. When the grinding depth is 3μm and the spindle speed increases from 3000r/min to 6000r/min, the roughness decreases from 0.33μm to 0.18μm; when the grinding depth is 6μm and the spindle speed increases from 3000r/min to 6000 r/min, the roughness decreases from 0.42 μm to 0.31μm. The greater the grinding depth, the smoother the roughness curve, the smaller the grinding
depth and the steeper the roughness curve. At different grinding depth, the range of roughness decreased significantly is also different. When the grinding depth is 3μm, the roughness decreased significantly when the spindle speed is 4000r/min; when the grinding depth is 6μm, the roughness decreased significantly when the spindle speed is 5000r/min.

**Figure 3.** Effect of spindle speed on surface roughness (workpiece feed speed 10m/min)

With the increase of the wheel speed to 6000r/min, all the roughness curves tend to be gentle, and the roughness value does not change much, indicating that the improvement of the roughness is limited by the increase of the wheel speed. With the increase of spindle speed, the number of times that a single abrasive particle appears on the machined surface in a unit time increases, and the high frequency superposition of wear marks in the same area of the workpiece surface reduces the workpiece roughness. The cutting speed of single abrasive increases and the cutting energy increases. The fracture of SIC particles is more rapid and complete, and the impact on the friction of aluminum matrix decreases. With the increase of grinding depth, the grinding marks become deeper, and the influence of high frequency superposition on roughness becomes weaker. The grinding heat between the grinding wheel and the workpiece increases, the aluminum matrix material is further softened, and the ploughing effect of the grinding marks is significant. The softened matrix material is not easy to form grinding debris, and it is not easy to completely and quickly break away from the processing surface, resulting in the matrix material sticking to the workpiece surface and reducing the surface roughness. SiC particles are easier to be pulled out from the aluminum matrix, causing secondary sliding damage to the soft workpiece surface.

As shown in Figure 4, they are roughness along the grinding direction and perpendicular to the grinding direction. The roughness along the grinding direction decreases with the increase of the wheel speed, and the roughness perpendicular to the grinding direction shows a similar trend, but it is obviously not sensitive to the change of the wheel speed.

**Figure 4.** Roughness in different grinding directions (grinding depth 2μm)

**Figure 5.** Effect of workpiece feed speed on roughness (DEP of different grinding depth)
It can be seen that the grinding depth increases and the roughness increases, but when the grinding depth reaches a certain value, the roughness no longer changes significantly. With the increase of grinding depth, different grinding feed speeds tend to have similar surface roughness, which shows that the influence of grinding depth on roughness is smaller than that of workpiece feed speed.

3.3. Grinding force
Fig. 6 and Fig. 7 show the change trend of tangential grinding force and normal grinding force with grinding depth. Obviously, with the increase of grinding depth, the grinding forces in both tangential and normal directions continue to increase. The increasing speed of grinding force is related to the feed speed of workpiece, and the increasing speed of grinding force is larger when the feed speed is faster; on the contrary, the increasing speed is smaller. With the increase of grinding depth, the contact arc length and contact area between the grinding wheel and the workpiece become larger, and the number of abrasive grains participating in cutting increases, so the grinding force becomes larger. With the increase of feed speed, the amount of material removed in unit time increases, and the contact frequency of abrasive grains with the removed workpiece material increases in unit time, which results in the increase of the impulse of the same abrasive grains to the removed workpiece material in unit time, which is manifested as the increase of grinding force.

4. Conclusion
The grinding characteristics of SiCw / 6061Al material are experimentally studied on a surface grinder with a metal bonded diamond wheel. The effects of different grinding parameters on the surface morphology, grinding quality (mainly roughness) and grinding force of workpiece are analyzed.

(1) Because of the great difference in physical and mechanical properties between the base phase AL and the enhanced phase SiC, the surface topography of the grinding process has obvious characteristics, showing a complex surface morphology. There are ploughing, holes, SiC fragments, cracks, and high temperature melting smear marks on the base;

(2) The rotational speed of the grinding wheel has a significant effect on the machining quality of the workpiece. The surface roughness increases with the increase of the feed rate and decreases with the increase of the rotational speed;

(3) In the process of grinding, the increase of workpiece feed speed increases the impulse of abrasive particles to workpiece materials in unit time, the increase of grinding depth increases the contact arc length between the grinding wheel and workpiece, and the grinding force increases with the increase of workpiece feed speed and grinding depth.
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Author brief:
Wang shaolei, male, 39 years old, doctor, associate professor, has been engaged in grinding research of hard and brittle materials for a long time.

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