Simulation of 3D Cutting Process of SiC_p/Al Composites

Kai Yang[1, 2], Qingfei Jiang[2, *] ,Xueyan Ma[2] and Xiaodong Xia[2]

[1]Post-doctoral Scientific Research Station in Nanjing General Hospital of Former Nanjing Military Region,Nanjing,Jiangsu 210000, China
[2]Army Aviation Institute, Beijing 101123, China

[*]jqfgzz@163.com

Abstact: Considering that it is difficult to obtain accurate results for 2D cutting simulation of SiC_p/Al composites, a 3D cutting simulation model for SiC_p/Al composites was established by using finite element analysis software ABAQUS. In this paper, material properties are assigned to Al-based and SIC particles respectively. The formation mechanism of SiC_p/Al composite surface morphology and the reasons of chip formation are analyzed. It provides reliable and accurate data support for optimizing the machining parameters and improving the surface processing quality.

Keywords: SiC_p/Al composites，3D cutting simulation，formation mechanism，chip formation，ABAQUS

1. Introduction

The secondary processing of SiC_p/Al composites is very difficult. The hardness of the SiC particles in the material is very high and the tool wear is severe during cutting. Many scholars or research institutes are analyzing the cutting simulation of SiC_p/Al composites. However, most of them are simulating two-dimensional cutting simulations of SiC_p/Al composites, and the SiC_p/Al composites are usually treated as homogeneous materials in the research process[4-6]. The true mechanism of material removal cannot be studied, and the reason for the surface defect cannot be obtained. The result is lack of accuracy. 3D cutting process simulation can more realistically express and intuitively reflect the entire machining process. The simulation results have important reference value. In this paper, SiC_p/Al composites were modeled and analyzed using the finite element analysis software ABAQUS Micromechanic Plugin to study the surface morphology formation mechanism and the reasons for the formation of chips. It provides reliable and accurate data support for optimizing cutting parameters and improving the quality of the workpiece surface.

2. 3D microscopic model finite element simulation of SIC/AL composites

2.1 Establishment of 3D Model of SiC_p/Al Composites

In this paper, the latest plug-in Micromechanic Plugin from ABAQUS is used. The geometric model of SiC_p/Al composites built using plug-in is shown in Fig. 1. The spherical inclusions are SiC particles, the SiC particle diameter is 40 μm, the volume fraction is 30%, and the overall size of the workpiece is 0.42 mm×0.24

mm×0.24 mm. Both the rake angle and rear angle of the tool are 5°.

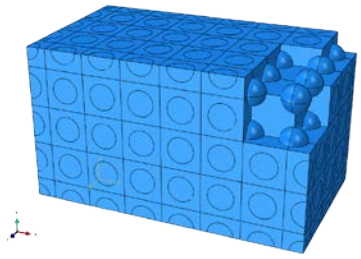

Fig.1 3D geometric model of SiC_p/Al composites

In the 3D model, due to the complex shape of the workpiece, it is difficult for ABAQUS to perform division of hexahedral elements. Therefore, Tetrahedron is selected in Mesh Control. Tool unit type Select C3D10.

2.2 Material properties

Before the finite element simulation, the material parameters need to be set. The workpiece material is aluminum-based silicon carbide, and the SiC particle content is 30%. The material is squeezed and casted after being mechanically agitated. The material has good thermal conductivity and mechanical properties. The tool uses a PCD tool. In order to make the simulation effect persuasive, the simulation of 2024Al is also performed in this paper. The physical properties of the above materials are shown in Table 1.

Table 1 Physical Properties of 2024Al, SiC_p/Al Composites and PCD Cutters[13 14 15]

Parameter	2024Al	SiC	PCD
Density(kg/m^3)	2.7×10^3	3.13×10^3	4.25×10^3
Elastic modulus(GPa)	70.6	420	1147
Poisson's ratio	0.34	0.14	0.07
Thermal expansion coefficient(K^{-1})	2.36×10^{-5}	4.9×10^{-6}	4×10^{-6}

3. Analysis of 3D FEM Cutting Simulation Results

3.1 Surface morphology

Figure 2 shows the topography of the machined surface after three-dimensional cutting simulation. As can be seen in the figure, the surface appearance after three-dimensional cutting is more intuitive and real. Due to the fracture of the hard and brittle SiC particles, the surface is left with uneven pits. When the particles are large fractures, "V"-shaped deep pits are generated; some of the particles are cut to the top, so only small fractures occur at the top. Part of the particles can also cause tearing of the matrix material at the same time as removal. The surface of the matrix material after cutting is also uneven.

The difference between the three-dimensional results and the two-dimensional results is that after the cutting, even if the SiC particles are not removed or only the surface is micro-fractured, gaps will occur where the SiC particles and the aluminum matrix meet. In the two-dimensional simulation, the bond between the particles and the matrix is very strong, which is reflected in the interface bonding strength in the

actual SiC_p/Al composite material, that is, the “interface debonding” phenomenon occurs in the three-dimensional simulation results. The reason may be that the combination of different material parts in the model established by the Micromechanic Plugin plug-in is not tight, and merely embedding the particles in the matrix material seems to lack the mutual constraint of some particles and the matrix.

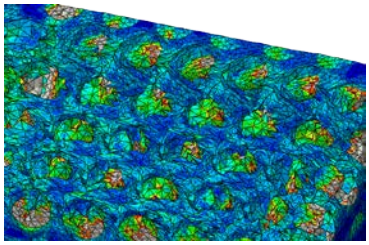

Fig.2 Surface morphology after cutting

3.2 Chip morphology analysis

Fig. 3 shows the chip morphology of the 2024Al alloy. Compared to the continuous chip of the 2024Al alloy, the chip morphology of the silicon carbide particle reinforced aluminum matrix composite is semi-continuous, as shown in Fig. 4 and Fig.5. The formation of SiC_p/Al sawtooth chip is mainly due to the inconsistent deformation of Al and SiC materials under the action of the tool. The presence of brittle hard SiC particles causes the anisotropy of the material.

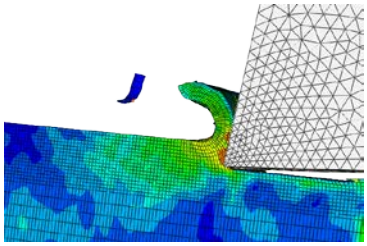

Fig.3 2024Al alloy 3D chip morphology

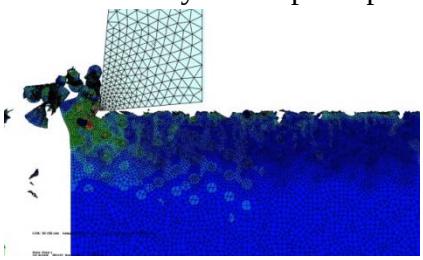

Fig.4 SiC_p/Al 2D chip morphology

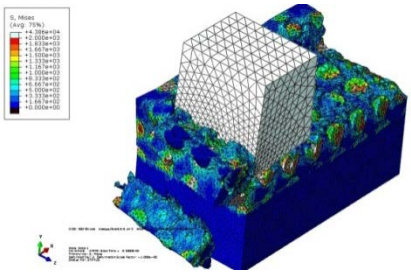

Fig.5 SiC_p/Al 3D chip morphology

For 2024Al alloy, the chip formation process is a typical shear-slip process. The tool first extrudes the workpiece. When the internal stress of the workpiece reaches the yield limit, the material of the cutting layer slides in the direction of maximum

shear stress. As a result, plastic deformation occurs, and the shear layer material flows when the shear stress continues to increase to the ultimate strength. When the flow direction is parallel to the rake face, the cutting layer material no longer slips, and the cutting layer material is separated from the block along the rake face.

The SiC_p/Al composites material contains hard and brittle SiC particles. Under the action of the cutter, the SIC particles undergo brittle fracture and the cracks propagate to form swarf. The deformation of SiC and Al is inconsistent, and the presence of SiC affects the normal formation of Al chips, making the chip layer thickness of Al uneven.

4 .Conclusion

In this paper, by using the ABAQUS Micromechanic Plugin plug-in, a three-dimensional microscopic model of silicon carbide particle reinforced aluminum matrix composites was established, and simulations of cutting simulations were performed. The surface morphology after cutting was analyzed. It was found that the surface quality of SiC_p/Al composites after cutting was poor due to the fracture of SiC particles, and the actual depth of cut in the fracture of silicon carbide particles was greater than the expected value. The chip morphology of 2024Al and SiC_p/Al was also analyzed and compared. The chip of 2024Al was continuous, and the chip of SiC_p/Al was zigzag. Based on the analysis of the causes of chip formation in both of them, it is concluded that the most important reason for the formation of saw-tooth chips in SiC_p/Al is that the deformation of plastic Al and brittle hard SiC is not coordinated.

References

[4] Yang J.Finite Element Simulation of Precision Milling SiC_p/Al and ExperimentAL Study[D].Harbin Insitute of Technology, 2012.
[5] Dong H, Du Y Z, Zhou L. Analysis of Three-dimensional Oblique Cutting of SiCp/Al Composite[J]. Tool Engineering, 2016, 50(7):24-27.
[6] Wang Y. the Study of the Formation Mechanism of Edge Defects During Milling of SiCp/Al Composites[D].Shenyang Ligong University, 2015.
[13] Zhu Y, Kishawy H A. Influence of alumina particles on the mechanics of machining metal matrix composites[J]. International Journal of Machine Tools & Manufacture, 2005, 45(4):389-398.
[14] Vogler M P, Devor R E, Kapoor S G, et al. On the Modeling and Analysis of Machining Performance in Micro-Endmilling, Part I: Surface Generation[J]. Journal of Manufacturing Science & Engineering, 2004, 126(4):695-705.
[15] Tan Y, Yang D, Sheng Y. Discrete element method (DEM) modeling of fracture and damage in the machining process of polycrystalline SiC[J]. Journal of the European Ceramic Society, 2009, 29(6):1029-1037.