# Study on the Formation Mechanism of White Layer Characteristics of Cutting Surface based on Finite Element Method

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## Abstract

**In this paper, the formation mechanism of the white layer characteristics of cutting surface of 7075 aluminum alloy was investigated. Deform software was used to simulate the high-speed cutting process of 7075 aluminum alloy. The difference between grain size and structure change was obtained, and the influence of grain change caused by plastic wear on the cutting surface was explained. In this paper, it is found that the "white layer effect" is a deformation mechanism, which is the result of the constant refinement of unconventional martensite growth obtained from plastic deformation.**

## Keywords

**7075 Aluminum Alloy; Deform; White Layer Characteristics of Cutting Surface; Grain Size.**

## 1. Introduction

The white layer is a kind of microstructure formed with an impact process. On the one hand, it has high hardness and good corrosion resistance. On the other hand, it is brittle and easy to cause early spalling failure. The white layer in high-speed machining has become a hot topic for scholars at home and abroad because of its extensive appearance and important influence [1]. In the process of high-speed cutting 7075 aluminum alloy, the material structure of machined surface changes due to factors such as high temperature, high pressure, and high strain caused by cutting friction, and the "white layer effect" occurs.

Traditional analytical methods and theoretical models cannot quantitatively analyze high-speed cutting. The appearance of finite element simulation technology provides a new idea for solving high-speed cutting problems. The finite element method has unique advantages in dealing with nonlinear problems and can visually reproduce the dynamic cutting process with the help of a computer, so it becomes the mainstream method for analyzing high-speed cutting problems. J.M. Wang et al. [2] established a two-dimensional orthogonal cutting simulation model of aluminum alloy 7075-T651 through AdvantEdge, and obtained the results that cutting force and cutting temperature increase with the increase of feed speed and cutting depth within a certain range. Y.H. Fan et al. [3] used the Voronoi method to conduct polycrystalline modeling. The finite element model of polycrystalline was obtained by controlling Voronoi seeds, as shown in Fig 1. Some control factors of burr in high-speed cutting are explained. Y. Zhang et al. [4] concluded through experimental research that the feed has the greatest influence on the thickness of the white layer.

**Fig 1.** Polycrystal model

In this paper, a two-dimensional cutting model of aluminum alloy 7075 was established based on Deform software, and the changes in crystal shape and size in the dynamic cutting process were simulated by cellular automata, and the formation mechanism of the white layer was finally well explained.

## 2. The Establishment of Finite Element Model

### 2.1. Materials and Constitutive Models

The constitutive model of material in cutting simulation is a mathematical model representing the macroscopic material properties of the material and is the key technology of the simulation manufacturing process. In the actual production of the 7075 aluminum alloy material milling processing has the characteristics of high strain, extreme temperature change, large deformation, etc. The 7075-aluminum alloy is a plastic material, and the workpiece material flow stress in the processing process also changes accordingly. Constitutive parameters of 7075 aluminum alloy are shown in Table 1:

**Table 1**. Constitutive parameters of the 7075 aluminum alloy

| A(MPa) | B(MPa) | m | n | $T_r$(K) | c | $\dot{\varepsilon}_0$ |
|---|---|---|---|---|---|---|
| 527 | 575 | 1.61 | 0.72 | 298 | 0.017 | 1 |

The formula of this model is shown in Equation (1) :

$$\sigma = (A + B\varepsilon^n)\left(1 + Cln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\left[-\left(\frac{T-T_0}{T_m-T_0}\right)^m\right] \tag{1}$$

Where $\sigma$ is equivalent plastic stress, $\varepsilon$ as the equivalent plastic strain, equivalent plastic strain rate is $\dot{\varepsilon}$, $\dot{\varepsilon}_0$ said plastic strain rate reference, $T_0$said processing materials in the process of the transformation temperature of plastic deformation, A is the initial yield stress, as the hardening coefficient, B, C as the strain rate coefficient, m for softening temperature coefficient, n in the process of machining hardening coefficient, A, B, C, m, and n are material constants.

### 2.2. Cutting Separation Criterion

Chip separation is an important part of cutting simulation. In this paper, the Johnson-Cook failure model [5] is used in conjunction with a constitutive equation to simulate metal failure deformation under an extreme strain environment. The calculation principle is shown in Equation (2) and Equation (3).

$$\varepsilon^f = [d_1 + d_2 \exp(d_3\bar{\sigma})][1 + d_4 \ln\dot{\bar{\varepsilon}}][1 + d_5\bar{T}] \tag{2}$$

$$D = \sum \frac{\Delta\varepsilon^p}{\varepsilon^f} \tag{3}$$

Where $\varepsilon^f$ is the equivalent plastic deformation, $\Delta\varepsilon^p$ is the equivalent plastic strain increment, *d1 ~ d5* are the separation criterion parameters of the material respectively, and $\bar{\varepsilon}$ is the stress triaxiality. When the separation parameter D=1, the separation criterion of the material is reached and chips are formed. The parameter values of separation criteria for 7075 aluminum alloy are shown in Table 2.

**Table 2.** Separate criteria parameter values

| $d_1$ | $d_2$ | $d_3$ | $d_4$ | $d_5$ |
|---|---|---|---|---|
| 0.11 | 0.572 | -3.446 | 0.016 | 1.099 |

### 2.3. The Establishment of Cellular Automata Cutting Model

In this section, the finite element cutting model of 7075 aluminum alloy is established by applying the cellular automata grain module in Deform software, as shown in Fig. 2. This model can not only analyze the stress-strain difference of alloy during cutting but also analyze the change of material grain shape and size during cutting, which can explain the formation mechanism of cutting the white layer well.

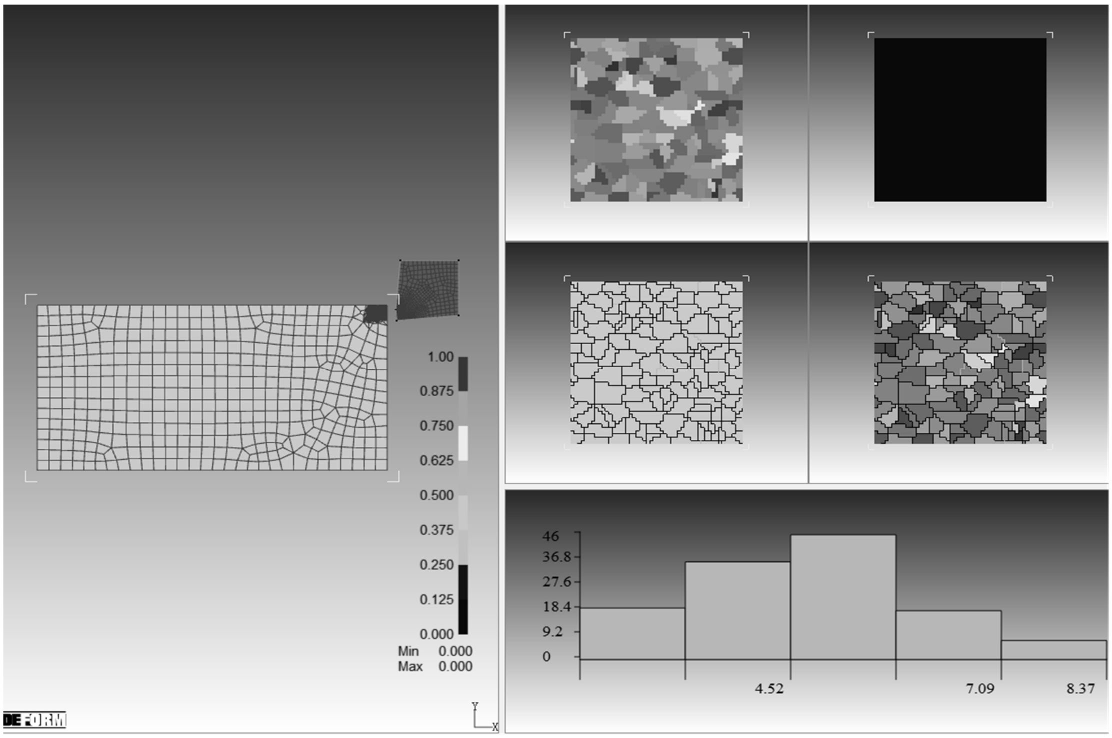

**Fig 2.** Cellular automata cutting model

## 3. Analysis of Finite Element Simulation Results

In this chapter, the changes in stress results are calculated by the finite element method, as shown in Fig. 3. The finite element results show that the stress around the cutting area is less than 543Mpa and the stress in the chip connection is about 600Mpa when the cutting tool and workpiece contact at the beginning of cutting 7075 alloys. As the cutting process continues, the high temperature and friction stress increase, and the stress near the machining area can remain below 543Mpa, but the stress value of some areas of the chip off machining reaches the maximum stress of 815Mpa.

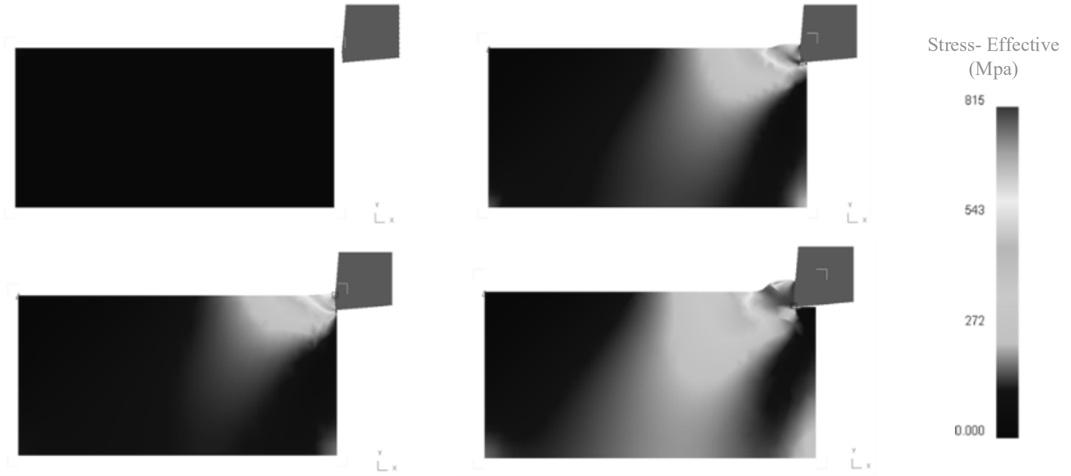

**Fig 3.** The result diagram of Stress

Cellular automata were used to simulate the grain morphology changes in the surface layer and surrounding area. Fig. 4 shows the surface grain morphology changes during the processing. It can be seen that the grain morphology of the cutting surface grows first and gradually refines evenly, resulting in a surface fuzzy layer.

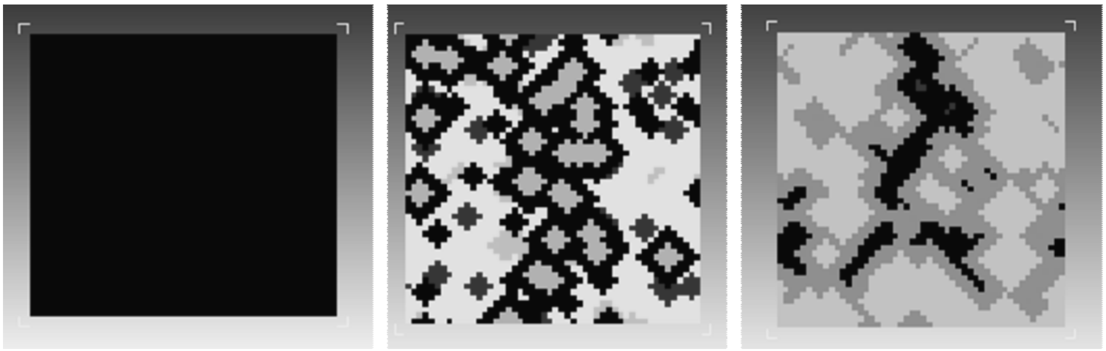

**Fig 4.** The change diagram of Surface grain morphology

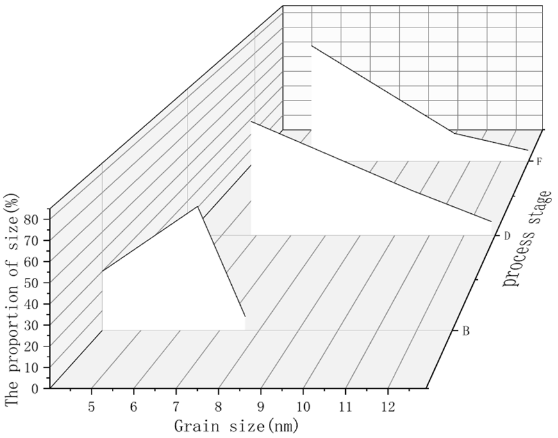

**Fig 5.** Grain size and proportion

As shown in Fig. 5, the proportion of surface grain size changes with the change in the processing stage (B-D-F). When the tool does not contact the workpiece, the proportion of small grain size accounts for about 60%. After the tool contacts the workpiece, the grain size increases gradually, and the proportion decreases linearly with the increase of grain size. After the cutting, the grain size of the surface layer presents a large proportion in the range of 7-10.3nm, and the average grain size decreases compared with the previous stage. The grain morphology changes in the area around the processing are shown in Fig. 6.

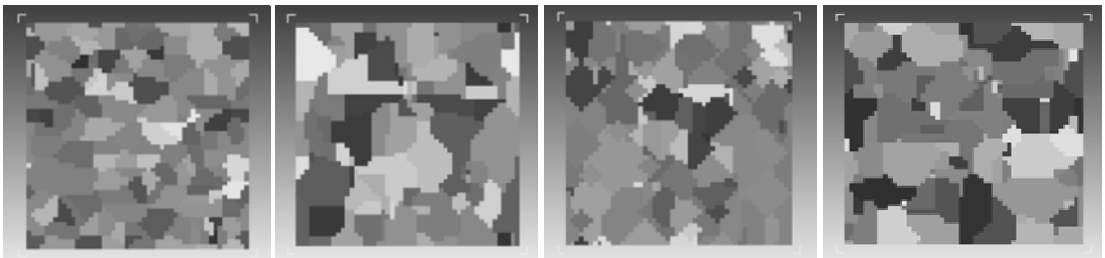

**Fig 6.** Grain morphology changes in the area around machining

## 4. Conclusion

In this paper, the finite element model of 7075 aluminum alloy cutting was established, and the cellular automata were used to simulate the grain change in the cutting process, and the following conclusions were obtained:

(1) In the cutting process of 7075 aluminum alloy, 543-815MPa high-stress value is mainly distributed in the chip area to be separated, which is conducive to chip separation.

(2) According to the cellular automata simulation results in this paper, in the cutting process, the white layer on the surface is mainly caused by the gradual thinning of part of the crystal growth.

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