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## Numerical study on springback with size effect in micro V-bending

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### Abstract

With the development of microforming technology, the demand on accuracy of the metallic micro components is elevating. While springback phenomenon which is inevitable during bending process, can cause unpredicted dimensional error, bringing difficulties to the downstream assembly, and let alone the springback in microforming as the measurements of tools and workpieces downsize hundreds even thousands times. This paper focuses on the springback effect that occurs after the micro V-bending a classic processing method to manufacture microparts. Numerical simulation has been conducted to investigate the size effect in terms of Voronoi tessellation and springback. A finite element (FE) model of the micro V-bending has been established by utilising ABAQUS/Standard commercial software. The grain sizes of 98, 152 and 201  $\mu\text{m}$  have been adopted in FE model to study the relationship between the size effect and springback angle during the V-bending process.

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### 1. Introduction

There is no doubt that microforming technology has attracted tens of thousands of attentions due to the prevalent usage of its matching products-micro parts. The increasing demand of micro-scale products (Jiang et al.,2006) for

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high accuracy and high quality has also inspired the development of microforming technology. The metal forming in traditional level has been progressed for centuries and a series of classic knowledge and theories have been established systematically by previous researchers. Nevertheless, it is common known that these macro-scale processing theories cannot be applied directly in micro-scale world with minaturisation due to size effect (Engel and Eckstein, 2002; Vollertsen et al., 2009; Chan et al., 2011).

While the scaling of the workpiece downsizes to micro-level, the parameters which may not be that important in conventional process begin to play an important role in controlling the accuracy of deformation, in the other way, determining the dimensions of processed workpiece. In micro-world, heterogeneity of workpiece is the primary issue needed to be considered. The scatter effect of grain behavior can be attributed to different grain sizes, shape and orientations which can be employed into each grain as a single element, functioning separately and mutually during the deformation process. Different effects of grains were investigated in detail in previous research (Chan et al., 2010), evolving from the scatter effect of testing samples strain-stress relationship on the corresponding grains one. In addition, nanoindentation test was also carried out with the simulation of the microcross wedge rolling process to identify the grain heterogeneity (Lu et al., 2013).

The main purpose of this study is to propose a finite element model combining Voronoi tessellation which is widely applied to generate polycrystalline aggregate and the grained heterogeneity, which can be well-reflected by the scatter effect of grain plasticity behavior to further develop FE model to execute more accuracy and reliable prediction in microforming process.

## 2. Numerical simulation setup with Voronoi tessellations

### 2.1. Voronoi tessellation assignment in ABAQUS/CAE

Voronoi tessellation has extensive application in scientific research (Zhang et al., 2005; Schiøtz et al., 1998). Specifically in materials science, polycrystalline microstructures are commonly represented by using Voronoi diagram because of its shape, distribution and irregularity (Simonovski and Cizelj, 2011). While limited computational research has illustrated the complete Voronoi tessellation realisation when is being performed in the FE model since it has been used as a functional approach adopted in polycrystalline materials research.

The way to generate Voronoi diagram numerically has been systematically stated in Matlab database, and in this section how to realise Voronoi tessellations composing the workpiece which is computationally represented by multiple grains, and each single grain contains grain interior and boundary according to Voronoi tessellation property into ABAQUS/CAE will be discussed.

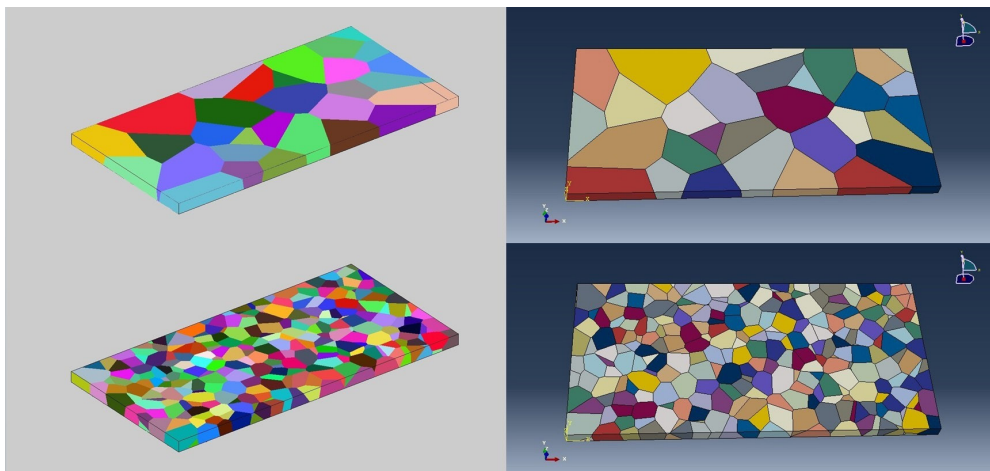


Fig.1. Voronoi tessellation in Matlab (left) and Abaqus/CAE (right) with 30 and 300grains

Firstly, Voronoi tessellation has been generated by means of computational software MATLAB. Voronoi tessellation program was debugged by authors, and then was plotted according to the function in MATLAB itself. After the generation and visualisation of Voronoi tessellation, all the topology information involved in the plot were extracted by MATLAB programming which will also generate a Python file including vertex and edges data simultaneously. Python programming language works as scripts in ABAQUS/CAE can accomplish tasks in ABAQUS with characteristics of less time consuming, less repetitive and more flexible operation. Instead of human input tediously, Python scripts can complete the setup with a large number of grains in GUI (ABAQUS/CAE) satisfactorily by typing given program statements.

The Python statements are decisive to generate Voronoi tessellation in ABAQUS. Since all the topology data of Voronoi tessellation will be delivered by MATLAB, the key factor is choosing the Python statements correctly, and then each Voronoi tessellation can be visualised and generated as an isolated part in GUI. Fig. 1 shows Voronoi tessellation in MATLAB and in ABAQUS/CAE respectively. In next section, grained heterogeneity will be implemented via Python scripting into each grain with a single plastic property in the FE model.

## 2.2. Grained heterogeneity

After Voronoi tessellation setup in the FE model, the workpiece will be equipped with given quantities grains, however, the grain boundary is just geometric feature unless each grain can be recognised by a certain property which can make single grain heterogeneous to each other. Different orientations, sizes and shapes of different grains have a momentous impact on size effect, causing heterogeneous deformation behavior and the scatter effect of material mechanical properties as shown in Fig. 2.

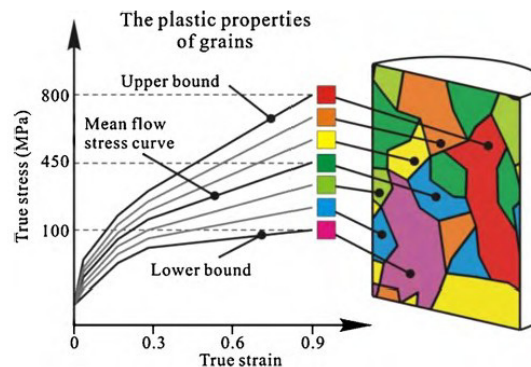


Fig. 2. Grain properties randomly assigned on the metallographies of the sample models (Chan et al., 2010).

The methodology adopted in this study is distinguishing grains with different strain-stress relationships, that is to say, every Voronoi tessellation will be rendered a plastic property in the FE model. However, it is not easy to assess the plastic property of each single grain involved in the workpiece. The upper and lower boundaries of the plastic properties of grains are confirmed by way of evaluating the degree of spread  $\delta(\epsilon)$  of the strain-stress curves of grains based on the scatter effect of testing sample strain-stress curves (Chan et al., 2010). The grain heterogeneity can be achieved after implementing the scatter effect of flow stress for grains into each Voronoi tessellation as an independent part shown in Fig. 3, which means all Voronoi tessellations are attributed with statistically three different plastic properties, and these have decisive influence on deformation behavior individually. In Fig. 4, green colors represent mean grain plastic property with yield stress at 123.54 MPa, blue and red symbolise the upper and lower boundaries of grain plastic properties with yield stress at 143.27 and 107.15 MPa respectively. It is clear that as the grain becomes larger, the more important role the grain heterogeneity will play. In finite element method simulation, the number of grains for each type of plastic properties is calculated with normal distribution probability function. The grain plastic properties are based on the research of Tsai (Tsai et al.,

2005) and extended to three different properties for each grain size. The mechanical properties of grains with  $152\ \mu\text{m}$  which are displayed in Fig. 5 have been distributed in workpiece randomly by python scripts.

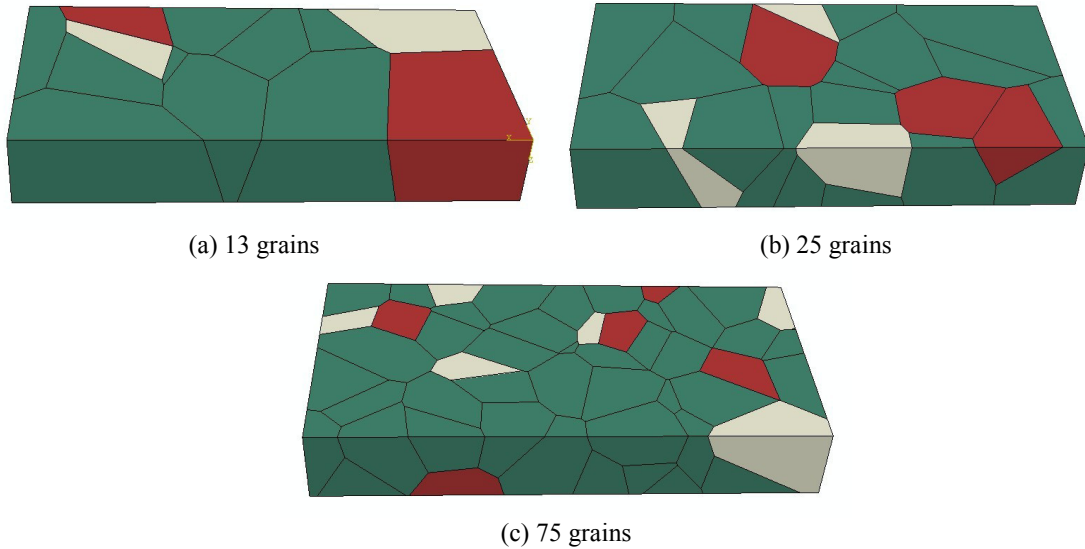


Fig. 3. Grained heterogeneity in workpiece with (a) 13 grains, (b) 25grains and (c) 75grains.

### 3. Numerical simulation procedure

Here we simulated micro V-bending process in the FE model, including the delicate punch and die are characterised with 90 degree convex-concavely, and the pertinent geometric parameters are: die gap = 0.8 mm, die depth = 0.4 mm, punch corner radius = 0.01 mm, punch stroke = 0.25 mm, friction coefficient = 0.04 (Li et al.,2002). The voronoied workpiece sized with  $1 \times 0.5 \times 0.15\ \text{mm}$ , and the V-bending model is shown in Fig. 5.

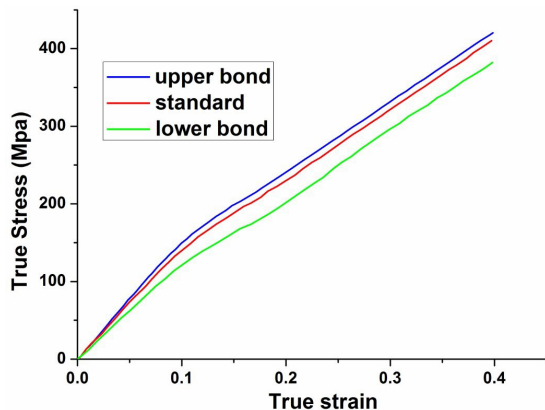


Fig. 4. Strain-stress curves of workpiece with grain size  $152\ \mu\text{m}$ .

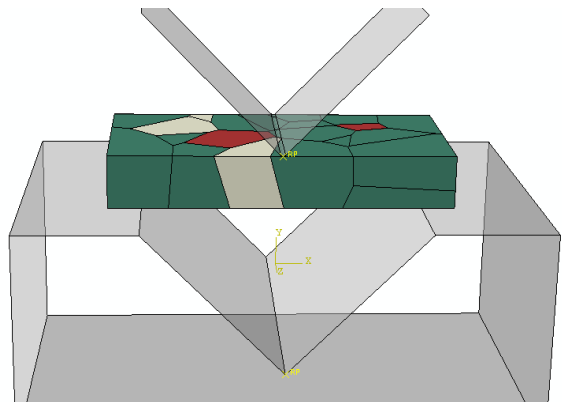


Fig. 5. Micro V-bending FE model with grain size  $152\ \mu\text{m}$ .

To demonstrate size effect for springback in micro V-bending, an implicit FEM package: ABAQUS/Standard is used to simulate the process. In this work, bending sample sized  $1 \times 0.5 \times 0.15$  is designed with 75 grains (grain size  $98\ \mu\text{m}$ ), 25grains (grain size  $152\ \mu\text{m}$ ) and 13 grains (grain size  $201\ \mu\text{m}$ ) involved respectively.

In order to investigate the influence of grain heterogeneity, the FE model is not set up as traditional asymmetrical one. Instead, the model is closer to the real physical experimental condition as the right and the left sides of the sample are not equal in terms of grain size and the scatter effect of grain mechanical properties. The eight node 3D linear brick and reduced integration continuum element C3D8R is adopted in the analysis and two rigid surfaces are used to simulate the punch and die since they are stiff components.

According the simulation result, it is apparent that the inhomogeneous deformation occurred during the bending process, Fig. 6 illustrates the final result of the micro V-bending. It can be observed that on the condition of uniform friction coefficient between the downside of workpiece and die surface, the right and the left sides of sample experience different level of bending and springback, and the neutral layer can be perceived. However, it is not located in the exact central of the workpiece. These two kinds of phenomenon could be caused by distinctive meshing in each grain in the FE model due to distinctive grain shape and size.

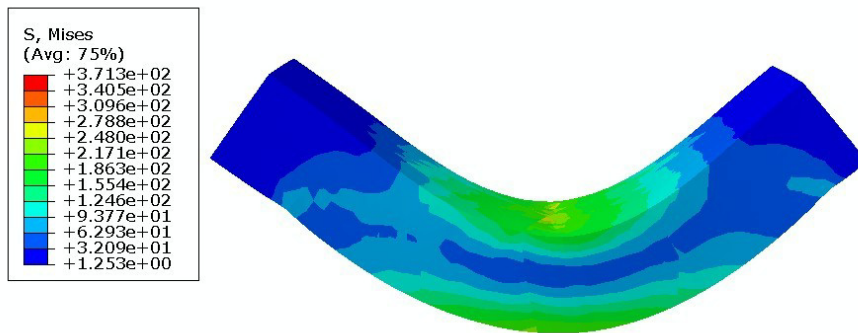


Fig. 6. Micro V-bending result after unloading.

Fig. 7 shows the final bending angle of different grain size sample after unloading, and it is obvious that the springback increases with an increase of grains size. Despite the influence of grain plastic properties, the increase of springback could be attributed to the decrease of grain boundary feature with minimisation. Although there are differences in grain plastic properties, when comparing to the huge quantities of grain boundaries in different grain size samples, these differences can be considered as minimisation. The grains in the material become less constrained, which facilitates the elastic recovery.

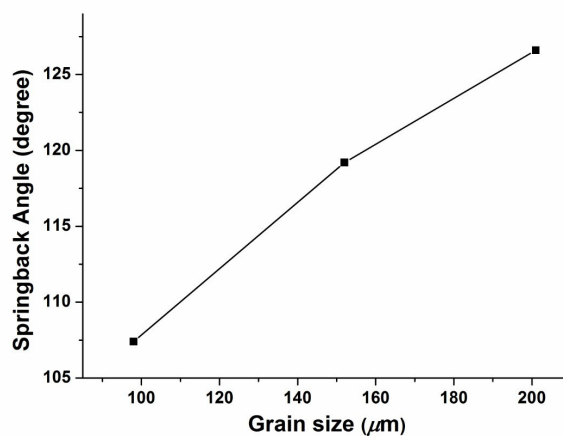


Fig. 7. Springback angle versus grain size.

#### 4. Conclusion

In micro-level, materials cannot be considered as homogeneous owing to the limited quantities grain involved in workpiece. The property of each grain will perform its role in the deformation process, especially the grains in deformed region. So it is essential to adopt grained heterogeneity.

When microforming simulation is going to be carried out, the scatter effect of grains mechanical properties can be obtained by traditional tensile tests, and it provides a simple and effective method to distinguish the difference of grains. Voronoi tessellation can imitate the microstructure of materials, and express grained heterogeneity graphically when being put into the FE model. The V-bending FE simulation result can display the inhomogeneous deformation during micro V-bending process, and it also shows that springback increases with grain size.

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