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# INFLUENCE OF INCLUSION ON INTERNAL DEFECT IN MULTI-STAGE EXTRUSION

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## Summary

Internal defects such as chevron crack occasionally occur in the process of cold extrusion or cold drawing. It is known that the existence and property of inclusion greatly influences the generation of the internal crack. However, in the plastic working field, research about the effect of the inclusion on the fracture is not theoretically analyzed. This paper describes effects of the physical property of inclusion on the internal fracture generation in the process. Prediction of fracture was evaluated by critical damage value calculated by the equation of Cockcroft & Latham and its change by the inclusion physical property such as size and stiffness was investigated.

Keywords: FE simulation, extrusion, internal defect, ductile fracture, inclusion

## 1 Introduction

In the ductile fracture, microvoids are generated by the peeling between second phase particle and matrix metal (**Figure 1**). And they grow by the effect of hydrostatic pressure and plastic strain and coalesce each other. This phenomenon is widely studied in the field of the fracture mechanics. Much kind of ductile fracture conditions are proposed and used also in deformation analysis of plastic working. However, they averagely handle the effect of inclusion, influence of size and distribution of the inclusion on fracture has not been clarified. In this study, base metal and inclusion were introduced as different objects in FEM analysis, the effect of the inclusion on the internal crack (chevron crack) is researched.

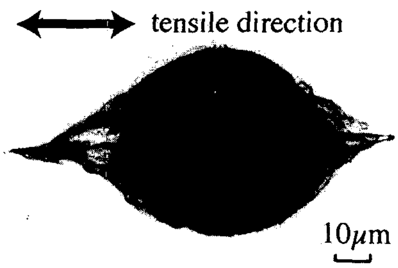



***Figure 1**: Void initiation on inclusion boundary*

## 2 Experiment method

Extrusion of 7 stages for the billet of 35.1mm diameter and 45.0mm height was performed under the condition of taper angle 30° (**Figure 2**). The reduction ratio of area on each stage of the process is shown in **Table 1**. The axial length of inclusion and internal defect was measured by the supersonic detector after each stage. **Figure 3** shows size ratio after each stage in initial inclusion length to be 1. It is showed that the size rapidly increases in the first to third stage in Figure 3. It can be supposed that defect occurs inside of material in the first or second stage.

***Table 1** : Schedule of reduction in area*

| Pass | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Reduction | 60 | 62.9 | 65.8 | 68.6 | 71.1 | 73.4 | 75.6 |

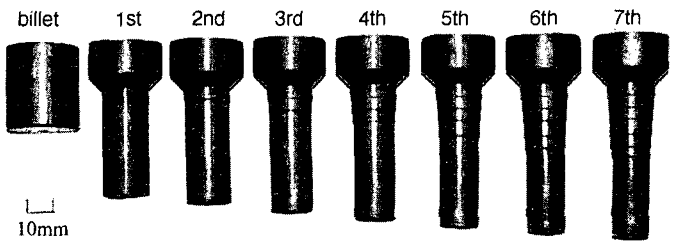



***Figure 2**: Appearance of the products in cold multistage extrusion*

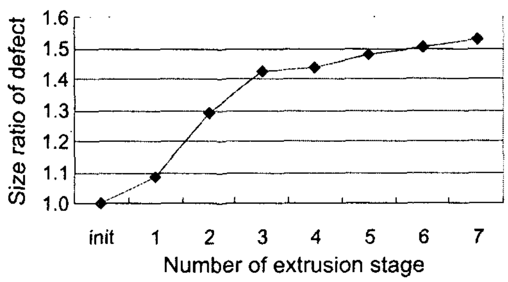



***Figure 3** : Size ratio change of defect at each stage*

## 3 Analysis method

### 3.1 Ductile fracture model

The equation of Cockcroft & Latham was used as ductile fracture condition [1], and damage value $C$ was defined by this,

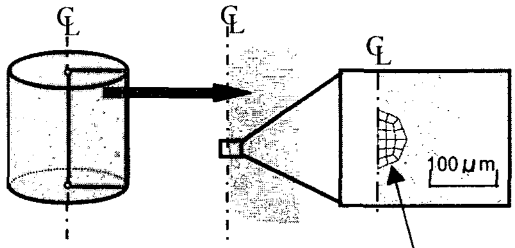
$$C = \int_0^{\bar{\varepsilon}_f} \sigma_{\max} d\bar{\varepsilon} \quad (1)$$

where, $\sigma_{max}$ is maximum principal stress, $\bar{\varepsilon}$ is equivalent strain, $\bar{\varepsilon}_f$ is fracture strain and $C$ is critical damage value.

In the analysis, general-purpose finite element analysis soft DEFORM-2D was used, and the base metal was handled elastic-plastic material (JIS SCr420H), and the tool was handled as a rigid body. Inclusion confirmed actually is about 100 $\mu$ m, and it was introduced to FE mesh on the center axis of material (**Figure 4**). Physical properties of the inclusion variously changed as shown in **Table 2**, and simulation was handled as axisymmetric problem. Boundary condition between inclusion and base metal was handled as perfectly sticking.

***Table 2*** *: Simulation condition of inclusion property*

| | E (GPa) | material model | number | spacing (μm) | size (μm) |
|---|---|---|---|---|---|
| model 00 | - | - | - | - | - |
| model 01 | 840 | elastic | 1 | - | 100 |
| model E21 | 210 | elastic | 1 | - | 100 |
| model P | 210 | ela-pla | 1 | - | 100 |
| model I100 | 840 | elastic | 3 | 100 | 100 |
| model I20 | 840 | elastic | 3 | 20 | 100 |
| model S300 | 840 | elastic | 1 | - | 300 |



(a) billet (b) FE mesh (inclusion)

***Figure 4*** *: Introduction of inclusion in FE mesh*

### 3.2 Determination of critical damage value

It is known that the stress state, especially the stress triaxiality, greatly gives the effect for generation of ductile fracture. It is necessary to decide the critical damage value under the stress condition that is similar to the actual process. The value was determined by notched round bar tension test [2]. In the test, stress triaxiality in the neck of specimen can be controlled by the notch radius.

## 4 Results and discussion

On model 01 which introduced the inclusion, there was a distribution of the maximum principal stress near the extrusion direction vertical end of the inclusion. It is a cause that the axial tensile stress becomes maximum in the position. In this area, mean stress and damage value also showed the maximum value (**Figure 5**). This tendency was also similar on other inclusion model. And, relationship between stiffness of the inclusion and maximum damage value in each stage is shown in **Figure 6**. In comparison with model 01 and E21 in which Young's modulus differs for 4 times, it increases the damage value of model 01 in which the stiffness is bigger. Comparison of the damage value in placing several

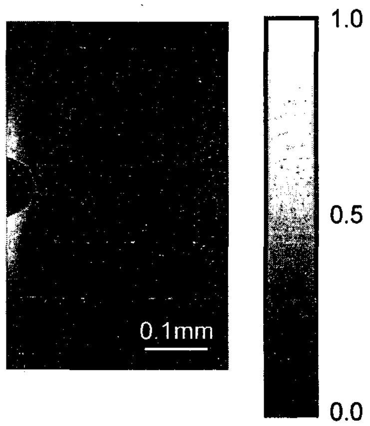



***Figure 5*** *: Damage value distribusion around inclusion (model01 1st stage)*

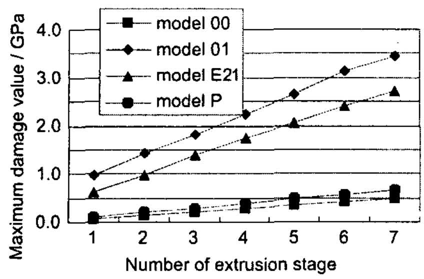



*Figure 6 : Effect of inclusion stiffness on damage value*

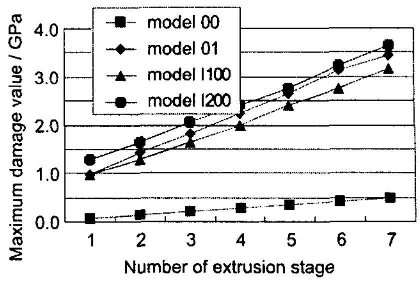



*Figure 7 : Effect of inclusion location on damage value*

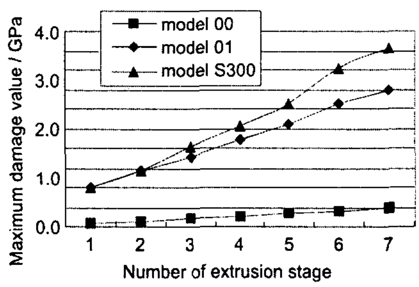



*Figure 8 : Effect of inclusion size on damage value*

inclusions on the billet central axis is shown in the **Figure 7**. Number and interval of the inclusion do not affect the damage value. When diameter of inclusion changes, the maximum value of the stress increases with increase of the value and the increasing rate of the damage also increases (**Figure 8**).

## 5 Conclusion

Base metal and inclusion were introduced as different object in FE simulation and the analysis was carried out. Influence of inclusion property on maximum damage value was investigated and following results were confirmed.

- When an inclusion exists on the center axis of material, maximum damage value was bigger than that of no inclusion case.
- Damage value increases with stiffness of inclusion.
- The damage value also increases with the increase in the stress level near the inclusion, when the size of the inclusion increases.
- Number and interval of the inclusion do not affect the damage value.

## References

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