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STRAIN ANALYSIS OF LATERAL EXTRUSION PROCESS①

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ABSTRACT The strain distribution of equal-cross section lateral extrusion (ECSLE) has been simulated by finite element method. Considering the effect of friction and the width of sample, the simulation results are very close to the reality. The simulated results showed that, around the corner of die, the strain is distributed by sharp layers, and the gradient of the layers is very large, which means that the deformation is just plane shear deformation; the larger the width of sample or the smaller the friction, the more uniform the strain distribution is.

Key words equal-cross section lateral extrusion finite element simulation strain equivalent true strain

1 INTRODUCTION

In recent years, a new kind of method, equal-cross section lateral extrusion (ECSLE), has been successfully used to make ultra-fine grain (UFG) materials[1-5]. The equal-cross section lateral extrusion (ECSLE) has a character that the dimensions of the deformed material or the workpiece could not be changed after the deformation, so the workpiece can be cyclically deformed to very large strain in a set of die.

Although there are some articles[5,6] reporting the strain calculating of simple equal-cross section lateral extrusion, how to accurately calculate the strain and the strain distribution of the practical equal-cross section lateral extrusion process, in which the friction should be considered, is not solved perfectly. As the growing development of the finite element method in metal forming field, the plastic theory could be easily and directly used to analyze the practical deformations in ECSLE.

In this paper, the strain distribution of equal-cross section lateral extrusion has been analyzed by a rigid-plastic finite element software H-FORGE2D[7]. From the simulated results, we can know more about the strain distribution and the effects of friction during the ECSLE process.

2 CALCULATION OF STRAIN DISTRIBUTION

2.1 ECSLE and S-type lateral extrusion deformation

After the lateral extrusion deformation, the cross section area of the workpiece may be increased, decreased or unchanged. If the cross section is not changed, the deformation may be called as equal-cross section lateral extrusion (ECSLE).

If the ECSLE process has two lateral extrusion angles, $+\theta$ and $-\theta$, it may be simply called as S-type lateral extrusion. The schematic of S-type lateral extrusion is shown in Fig.1.

During the ECSLE process, in any case of that the cross section is circle, polygon or other shape, the deformation of ECSLE is just plane strain deformation.

2.2 Calculating results

According to the supposition mentioned above, the true strain and equivalent true strain of ECSLE process have been analyzed by geometry method in detail in Ref.[8]. The derived formulae are as follows. In that analysis, the effect of friction is not considered.

$$e_1 = \ln(\sec\frac{\theta}{2} + \mathrm{tg}\frac{\theta}{2}) \quad (1)$$

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$$e_2 = 0 \quad (2)$$

$$e_3 = \ln(\sec\frac{\theta}{2} - \mathrm{tg}\frac{\theta}{2}) \quad (3)$$

$$\bar{e} = \frac{2}{\sqrt{3}}\ln(\sec\frac{\theta}{2} + \mathrm{tg}\frac{\theta}{2}) \quad (4)$$

where θ is the lateral extrusion angle, e_1, e_2 and e_3 are the true strain, $\bar{e}$ is the equivalent true strain.

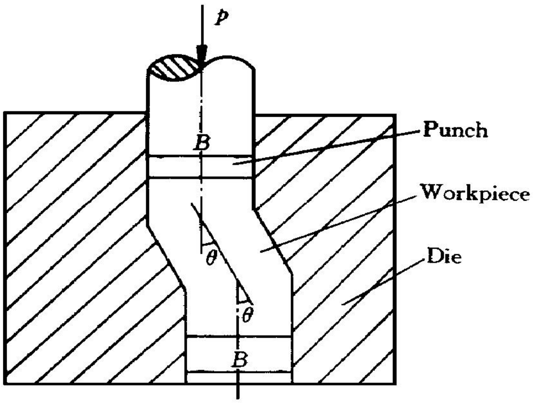


Fig.1 Schematic diagram of S-type lateral extrusion

The simulating results are shown in Figs.2 and 3, in which the effect of friction and the width of sample have all been considered.

As shown in the simulation results, at the beginning of the deformation, the deformation is not uniform; with increasing deformation, it gradually becomes uniform or homogeneous.

Around the corner of the die, the strain is distributed by sharp layers, and the gradient of the layer is very large, which means that the deformation is just plane shear deformation.

For considering the effect of friction and the width of sample, the simulating results of the strain distribution would be very close to the reality. In fact, the two factors have more significant influence on the strain distribution. The larger the width of sample, or the smaller the friction, the more uniform the strain distribution. In this case, the results calculated by Eqs. (1) ~ (4) would be very close to the simulation results. The results are shown in Table 1.

As for the S-type lateral extrusion process, the strain distributions are shown in Fig. 4. Around the corner, the strain is also distributed by sharp layers, and the deformation is uniform or homogeneous.

When $\theta = 20°$, the equivalent true strain is about 0.42 ~ 0.48 calculated by H-FORGE2D, and 0.405 calculated by Eq.(4); when $\theta = 30°$,

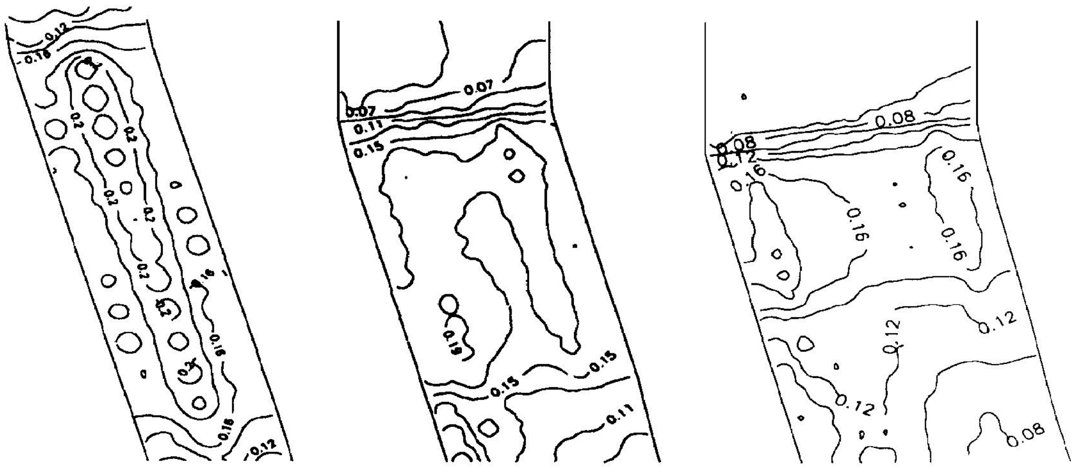
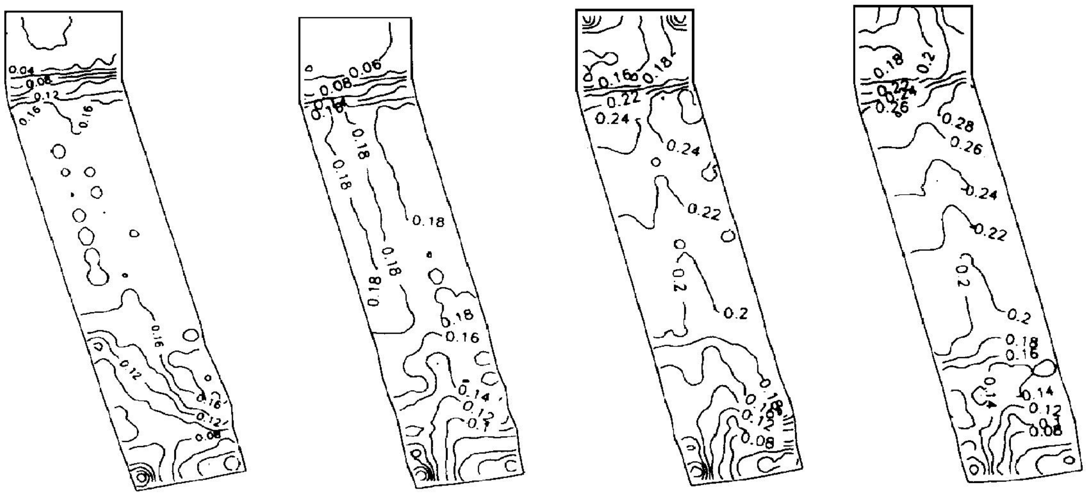


Fig.2 Equivalent true strain distribution with different widths after ECSLE deformation ($\theta = 15°$, $m = 0.26$)

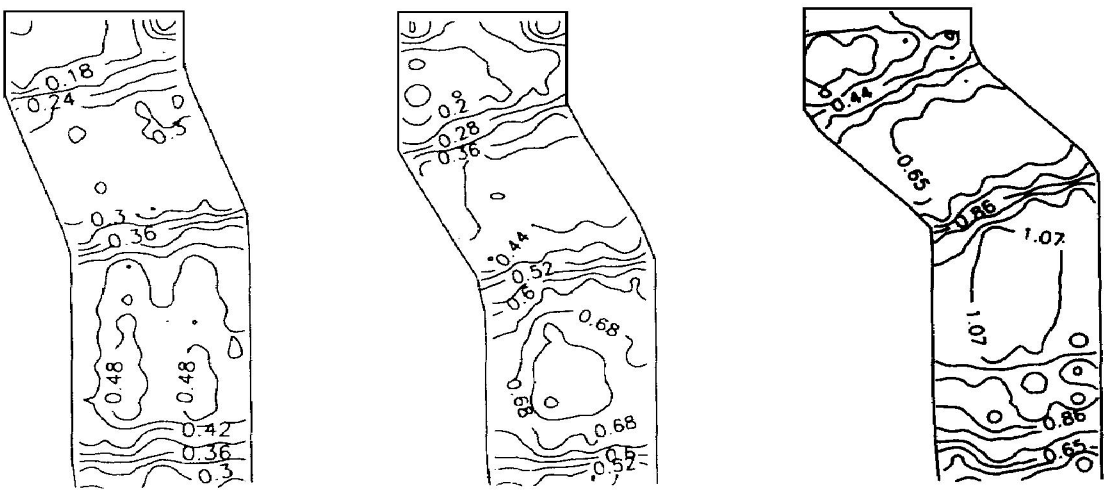
(a) — $B = 10$ mm; (b) — $B = 20$ mm; (c) — $B = 30$ mm



(a) (b) (c) (d)

Fig.3 Equivalent true strain distribution with different friction factors after ECSLE deformation ($\theta = 15°$, $B = 20$ mm)

(a) — $m = 0$; (b) — $m = 0.13$; (c) — $m = 0.4$; (d) — $m = 0.5$



(a) (b) (c)

Fig.4 Equivalent true strain distribution after S-type lateral extrusion deformation ($m = 0.26$, $B = 20$ mm)

(a) — $\theta = 20°$; (b) — $\theta = 30°$; (c) — $\theta = 45°$

the equivalent true strain is about 0.68 ~ 0.76 calculated by H-FORGE2D, and 0.612 calculated by Eq.(4); when $\theta = 45°$, they are about 1.0 ~ 1.07 and 0.931, respectively.

All in all, the equivalent true strain may be calculated by Eq.(4) or by H-FORGE2D. The results are close, when the strain is small and the width of sample is large or the friction is small. The results calculated by H-FORGE2D would be close to the reality, because of considering of the effect of friction and the width of sample.

Table 1 Calculated results of the equivalent true strain of ECSLE

θ/(°)	B/mm	Equivalent true strain	
		By Eq.(4)	By H-FORGE2D
15	10	0.152	0.16 ~ 0.20
	20		0.15 ~ 0.17
	30		0.14 ~ 0.16
20	20	0.203	0.20 ~ 0.24
30	20	0.306	0.32 ~ 0.36
45	20	0.466	0.52 ~ 0.56

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