COMPARATIVE ANALYSIS OF BEHAVIORS OF METAL FORMING INFLUENCED BY FRICTION OF TOOL

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Based on the visioplasticity method, a series of plane-strain extrusion experiments of aluminum (A1050) billets were carried out under the different lubricating conditions, and then the experimental results were analyzed quantitatively. An introduced friction free model makes it possible to comprehensively compare and analyze the effects of friction of tool on the plastic flow characteristics of material at the given lubrication. The experimental and analytical results show that the frictional constraint of tool greatly affects not only the plastic flow of material but also its deformation characteristics, and that the visioplasticity method is available in analyzing behaviors of metal forming influenced by friction of tool.

Key Words: friction, lubrication, deformation zone, material flow, velocity, effective strain

1. Introduction

For a few decades, one of the concerned problems is the effect of tool friction on the material flow and sliding surface in a metal forming process, because it influences not only the plastic flow characteristics of billets but also the quality of extrusion products. But so far, most researches focused on the frictional mechanism, computations of friction between tool and billet, lubricants and so on[1)-5)]. It is difficult to find the papers on comprehensive comparative studies of the effects of frictional constraint on material's flow characteristics and the surfaces of billet and tool. In our present investigation, an friction-free model was specially introduced as a comparative criterion, a series of plane-strain extrusion experiments were carried out using the pure aluminum (A1050) billets under the different lubrication conditions to compare the effects of frictional constraint on the material flow and deformation characteristics of a billet and the sliding (contact) surface in the deformation zone quantitatively. The detailed experimental and analytical results will be presented in the following parts.

2. Experiment and analysis procedure

2. 1 Experiment
A series of comparative plane-strain extrusion experiments of the pure aluminum (A1050) billets were

carried out under the different lubricating conditions Fig.1 explains the experimental conditions in detailed. The square grid patterns spacing 1mm×1mm were machined on the observation planes of the billets before experiments as illustrated in the same figure. Fig.1 (a) represents one set of symmetrical billets, sized 80mm×30mm×10mm, with respect to the contact plane (surface) between the left and right half billets, which were composed of four identical billets (80mm×15mm×5mm). This case can be considered as a friction-free model, in which there is nothing but normal press acting on the sliding plane, for the relative motion does not take place on the plane between the left and right half billets when they are extruded. Fig.1 (b) represents two identical billets forming one combination billet which keeps contact with the plane plate tool. Then, some frictional constraint will occur between the billet and plane plate tool during extrusion in accordance with the lubrication condition. It should be noted that the sliding plane in Fig.1 (b) is the surface of a straight plane tool with no bend section. Therefore, the force applying on a billet resulting from the plane plate tool is only the frictional constraint.

Our plain strain extrusion experiments were carried out and stopped abruptly at the steady state extrusion conditions. Then, the extruded billets were taken out from their containers and separated again to observe the distorted grid patterns on the observation planes.

The contrasting experimental conditions are given in table 1.

2.2 Analysis procedure
In order to obtain the values of velocity, strain rate, strain and stress in the deformation zone of the extruded billet

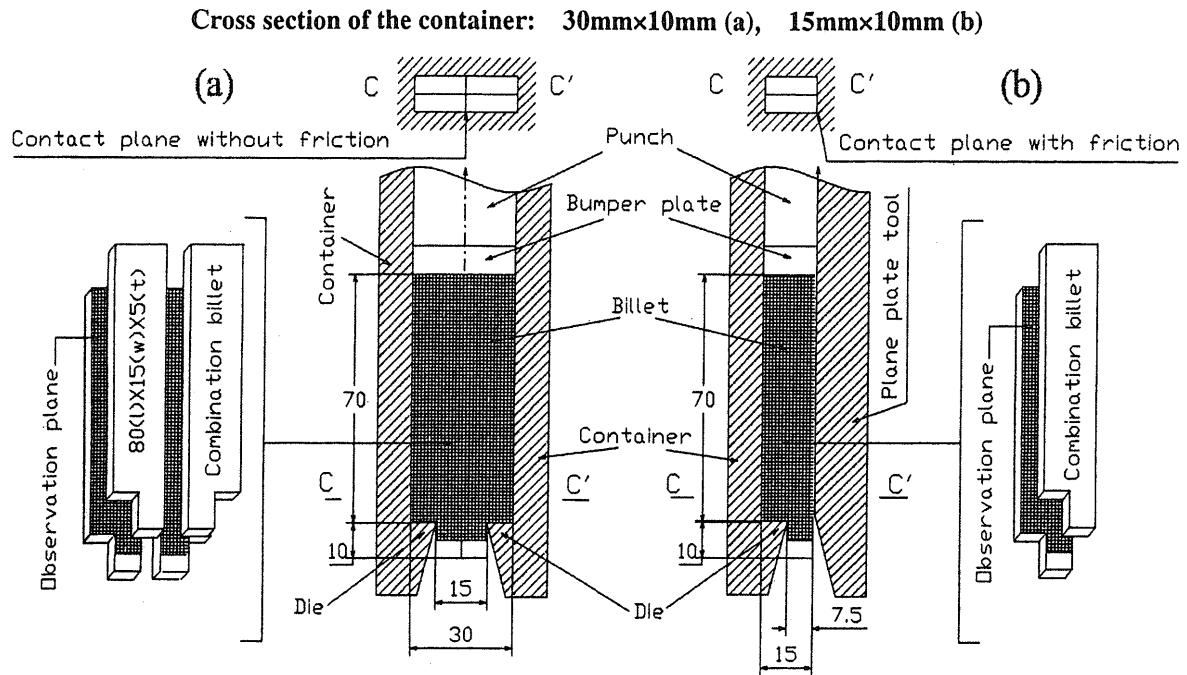**Cross section of the container: 30mm×10mm (a), 15mm×10mm (b)**

Fig.1 Sketch of the experimental apparatus and billets

under the actual conditions without any assumptions, the visioplasticity method[6)-10)] starting from the observation of flow field (flow line pattern) of the material having been extruded was adopted in our study to analyze and compare the results under the different frictional constraint in accordance with the lubricating condition. Fig.2 shows the flow chart of analysis procedure of the plane strain extrusion experiment and computer analysis by the means of the basic equations under the given coordinate system.
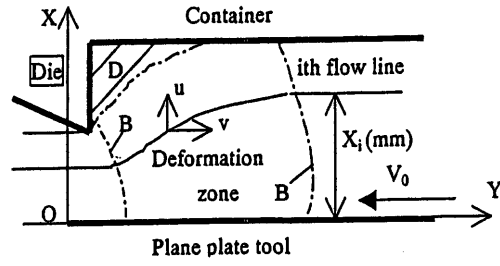
3. Results and discussion

Considering our aim at observing and analyzing the effects of frictional constraint of tool on the material flow, deformation characteristics and sliding (contact) surface of a billet in deformation zone, the distorted grid pattern was photographed at four positions locating at the bottom of billet near the (contact) sliding plane (including local (contact) sliding plane) on the observed plane, shown as in Fig.3 (a). The vertical lines in photographs denote time reference lines; the horizontal lines are flow lines, illustrated in Fig.3 (b). From the entrance of the deformation zone to its exit (from (4) to (1)), the distance between two neighboring time reference lines gradually become larger and larger, so we can conclude that the deformation velocity also get faster and faster from the entrance to the exit in the deformation zone for every case. For the friction free case (FF), because there is no friction acting on the contact plane, the vertical lines at the bottom are

perpendicular to the contact plane. So for the case with lubricant (L150), the frictional constraint along on the sliding plane near the entry of deformation zone may be have a little value because of the perpendicular vertical lines; from the middle part to the exit along the sliding plane, the vertical lines go to oblique towards the extrusion direction and their inclination are confirmatively caused by friction between tool and billet.

Table 1 Experimental conditions

Lubricant on the container wall: Paraffinic mineral oil (ISO-VG460)		
Extrusion ratio: 2.0		
Extrusion temperature: $\cong 24°C$ (Room temperature)		
Billet: Annealed aluminum (A 1050, HV25)		
Tool: SKD11, HV650		
Notations	Contrasting conditions on the contact (sliding) plane	Ram speed V_0
FF	Without friction	4.84 mm/s
L150	With lubricant Liquid paraffin (ISO-VG32), quantity = 15 mg.	4.97 mm/s
L001	With little lubricant Paraffinic mineral oil (ISO-VG7), quantity <= 0.1 mg.	4.95 mm/s

X / Container

Die D

ith flow line

u

v

Deformation

zone B

X_i(mm)

V_0

O

Y

Plane plate tool

B: Deformation boundery   D: Dead zone

Observe the distorted grid pattern and digitize the flow lines by the series of (X, Y) data pairs

Calculate the flow functions ψ_i along flow lines and at the points of the square grid

Flow function of ith flow line, $\psi_i = X_i|V_0|$ (1)

where, V_0 (mm/s) is ram speed and X_i distance of ith flow line measured in undeformed zone from the axis X=0

Calculate the velocity components and strain-rate components at the points of the square grid

Velocity components, (mm/s)

$$u = \partial\psi/\partial Y, \quad v = -\partial\psi/\partial X \quad (2)$$

Strain-rate components, (s⁻¹)

$$\dot\varepsilon_X = \frac{\partial u}{\partial X}, \quad \dot\varepsilon_Y = \frac{\partial v}{\partial Y}, \quad \dot\gamma_{XY} = \frac{\partial u}{\partial Y}+\frac{\partial v}{\partial X} (3)$$

Calculate the effective strain-rate at the points of the rectangular square grid and along flow lines

Effective strain-rate, (s⁻¹)

$$\dot\varepsilon = \frac{2}{3}\sqrt{3\dot\varepsilon_X^2 + 3\dot\gamma_{XY}^2/4} \quad (4)$$

Calculate the effective strain along flow lines

Effective strain along the flow line

$$\varepsilon = \int \dot\varepsilon dt \quad (5)$$

Fig.2 Coordinate system and flow chart
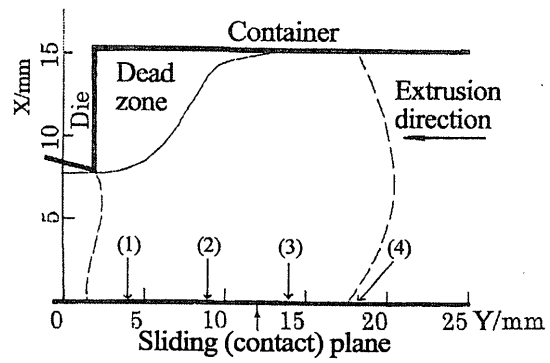explaining the analysis procedure

For the case with little lubricant (L001), the phenomena and situation occur same as in the case L150, but the degree of inclination of vertical lines is bigger than one in L150, which indicates that the friction exerting on the sliding plane also has a larger value. By comparing three cases with different lubricating conditions, the distortion of grid pattern of billet has a relevant relation with the frictional constraint of tool in correspondence with lubrication construction, so the conclusion can be reached that the more severe a grid pattern at the bottom of a billet distorts, the stronger the friction between tool and billet influences the plastic deformation of material.

For the purpose of further quantitative analysis, the extruded billets were photographed to record the plastic flow of material under the steady state, flow lines and distorted grid patterns are displayed clearly on the observation planes. After digitizing those amplified photographs of the observation planes in data pairs (X, Y), the deformation zones, in which variations of the parameters describing plastic flow characteristics will start from on the entry boundary and terminate on the exit boundary, dead zones and distribution of velocity can be obtained. Fig.4 indicates the three-cases' deformation zones, dead zones and their distribution of velocity, which illustrate that two cases (L150 and L001) with frictional constraint almost have the same deformation zones, these two deformation zones are smaller than that of the friction free case (FF) although they all have the same dead zones, and that three cases have the same shapes at their tops but the exit boundary of friction free model obviously lags behind those of the others. These phenomena mean that the frictional constraint of tool mainly affects sliding plane and its surrounding area of a billet in a metal working process.

Fig.5 (a) are topographic maps of relative velocity (V/V₀) in 3D made of the values at nodes in the deformation zones for three cases, which present material's plastic flow characteristics. According to them, we can find that velocities increase progressively from their entries to exits, and reach the maximum values in the vicinity of their exits. In addition to that increase in the case with little lubricant (L001) varies slower than in two other cases, their changes of velocity conform to the continuous condition of plastic flow. The respective subtractions of velocity for the case without friction from other two cases with frictional constraint are given in Fig.5 (b) so that the effect of tool's friction on the material's plastic flow can be clearly explained. Obviously, the effect in case L001 is greater than in L150.

Similarly, we adopt two-dimensional maps of effective strain, which present material's deformation property, to express our results of calculation, illustrated in Fig.6 (a). The distribution of effective strain for two cases with frictional constraint resembles each other in shape and has the similar variation from their entries to

(a) Positions of the observed points

Container

Dead zone

Die

Extrusion direction

X/mm

(1) (2) (3) (4)

0 5 10 15 20 25 Y/mm

Sliding (contact) plane

(b) Photographs of the observed points   1mm

(1)
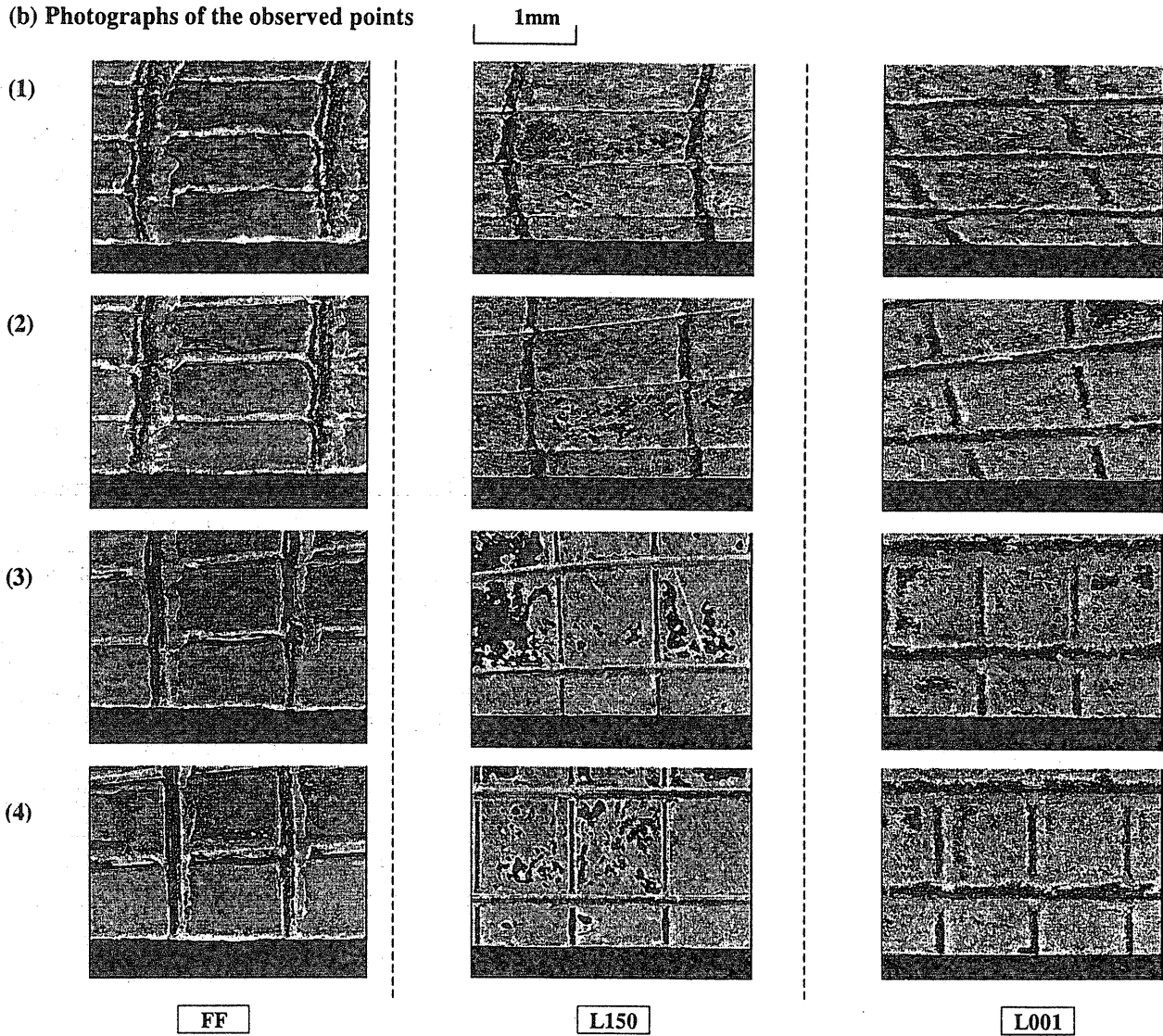
(2)

(3)

(4)

FF   L150   L001

Fig. 3 Figures representing the positions of the observed points (a), photographs of the observed points (b)

exits, but the effective strain distribution of friction-free case differs from one of them, especially, in the middle part. We respectively subtracted effective strain for

cases with frictional constraint from one for case without friction; then the 3D topographic maps of effective strain are obtained, shown as in Fig.6 (b). They show that their
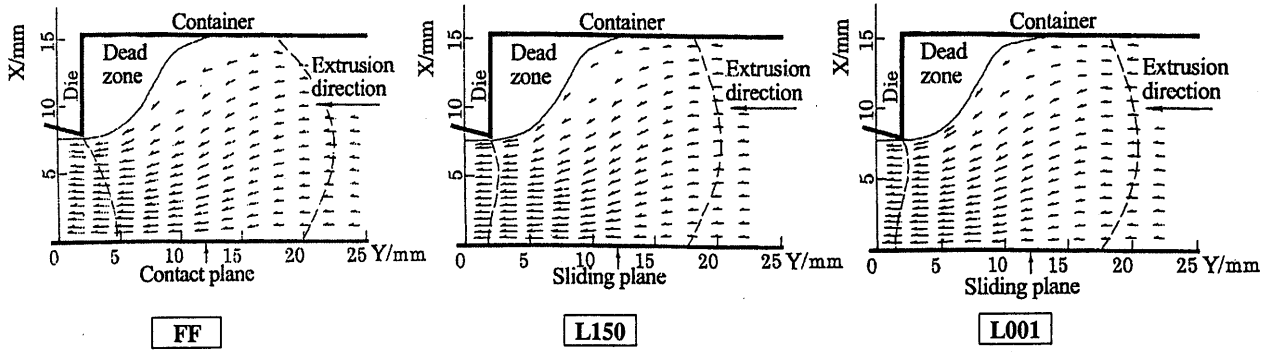
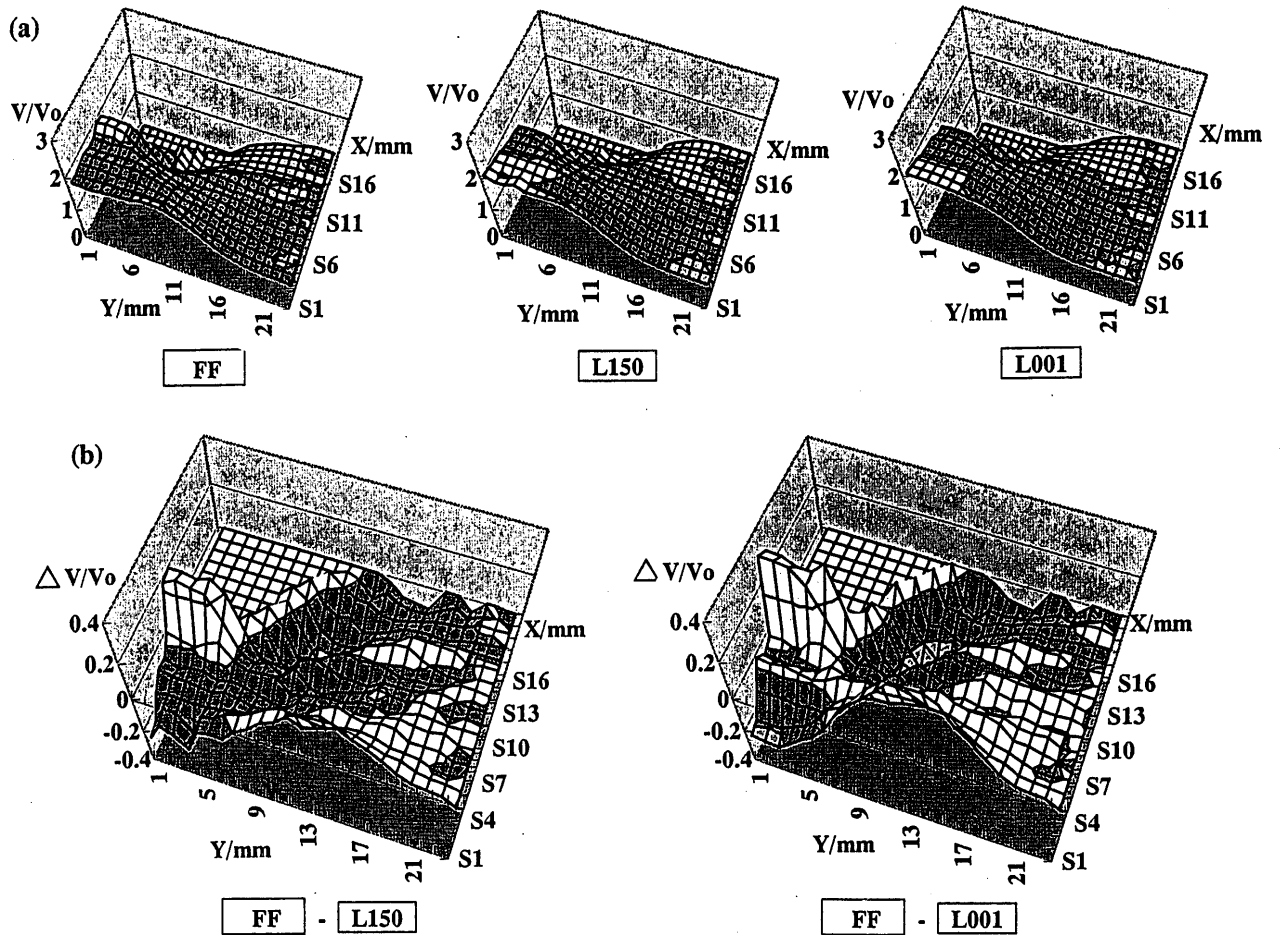Fig.4 Dead zone, deformation zone and distribution of velocity

Fig. 5 Figures representing distribution of velocity (a), difference of velocity (b)

difference principally distribute at the lower middle part, especially concentrate on the bottom in the middle area of the deformation zone, and just as the description of effect of friction of tool on the material's plastic flow in above section, so the difference between friction-free model (FF) and the little lubricant case (L001) has a bigger value.
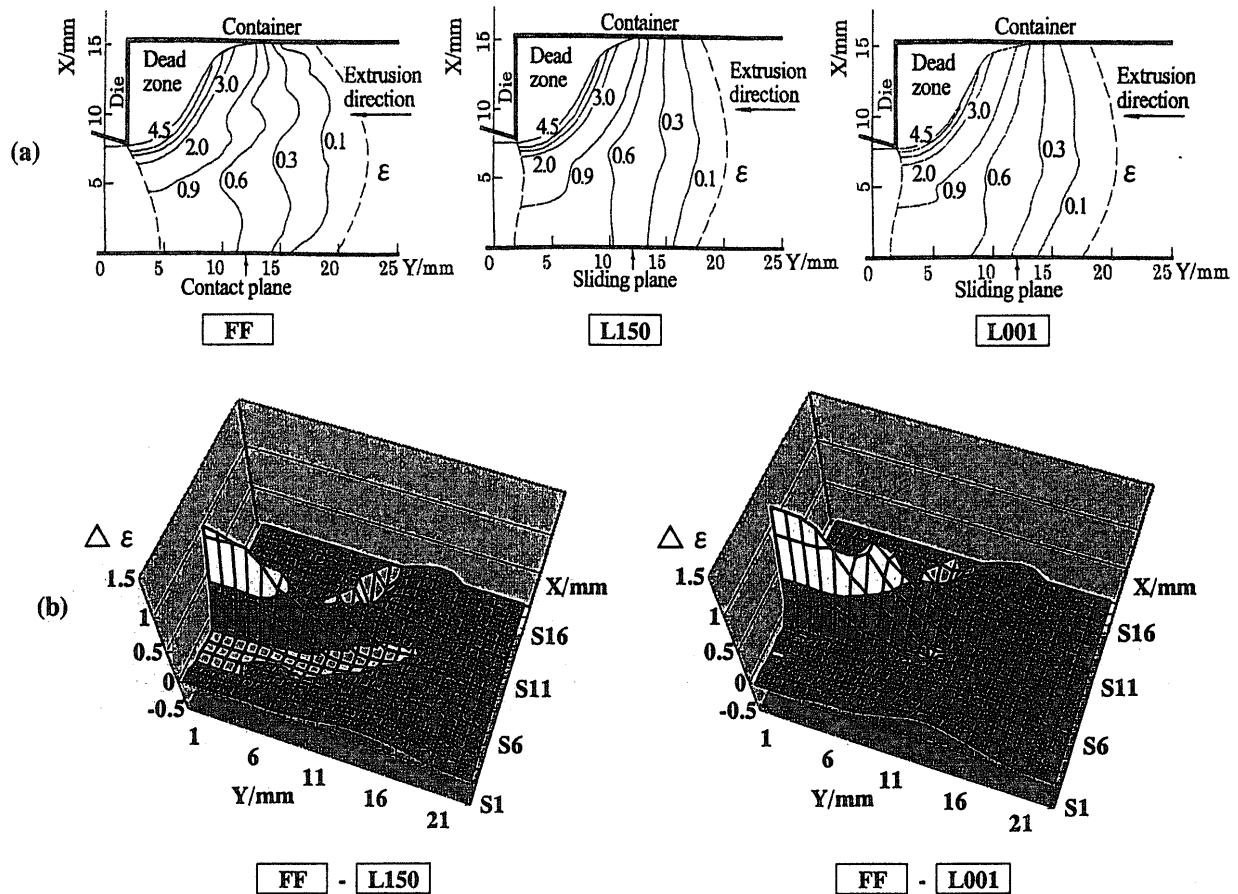
4. Concluding remarks

Fig.6 Figures representing contour maps of effective strain (a), difference of effective strain (b)

The above mentioned experimental and analytical procedure and results indicate that the visioplasticity method is available in quantitatively analyzing the effects of tool friction on the plastic flow of material and its deformation characteristics and sliding (contact) surface in a metal forming process, that the introduction of the friction free model makes it possible to comprehensively compare and analyze the effects of frictional constraint of tool on the plastic flow characteristics of material under different lubrication conditions, and that the frictional constraint of tool, as one of external constraints, affects not only the plastic flow of material but also its deformation characteristics.

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