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*Research Article*

# SMALL BILLET FORMING OF POROUS SINTERED COPPER SHEET

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**ABSTRACT:**
*This study aims at forming small billets on metal sheet which is fabricated as a porous blank by using powder metallurgy technique. Pure copper disc was fabricated in 50% porosity and used as specimen for small billet forming. Thickness of the sintered specimen is 2~3mm and small billet was extruded into die cavity by punch indentation at extrusion ratio 4. Diameter of the die is 1.0mm. As the results, In the case of same punch force, a billet height of porous specimen became longer than conventional pure copper. When specimens were extruded at the same punch stroke, porous specimen showed little shorter billet height than the conventional one due to occurrence of shrinkage, but its punch force became 33% lower. Billet height became more longer in case of thicker sintered specimen. It is concluded that the porous specimens is useful to forming a small or micro billet with lower punch force.*

**Keywords:** *Plastic forming, powder metallurgy, porous metal, extrusion*

## 1. INTRODUCTION

Recently, the rapid growth of mobile electronic devices has expanded the demands for manufacturing of small metal parts. It is well known that typical metal forming process such as cold forging brings great advantage for mass production of metal parts in comparison with cutting process. However, with decreasing the size of metal parts, transferring of blank/billet becomes difficult due to increase of frictional effects in handling by robot hands. Hirota *et al*., have suggested small billet forming of metal sheet to conduct forging process for miniature size metal parts [1]. In the process, extruded small billet remains on the sheet surface and it can easily locate to next die forging stage by handling and transferring of the sheet. Finally the small billet is forged to appropriate shape by proper die set, thus the miniaturization of metal forging process becomes achievable. However, since the contact area / volume ratio in the desired small billet shape increases with decreasing the processing size, friction loss between tool and billet becomes larger, and comparatively high forming pressure will be applied [2]. It means that the extruded billet height is clearly restricted by the yield strength of the punch and die, therefore aspect ratio of final forged parts restricted. Therefore special material properties will be demanded for the mass production of small metal parts by using existent metal forming techniques. Since the porous sintered metal has compressibility, it shows quite different yield property from conventional Von-Mises yield criterion. Especially in case of low density porous media, yield strength that is indicated in compression stress-strain curve shows very low with larger strain [3]. It is expected that the porous sintered materials avoid pressure increasing in the miniature forging process and achieve higher billet height in the small billet forming process. This paper proposes using porous sintered metal as a raw material for miniaturizing cold forging process. Small billet forming of porous sintered copper material has been carried out.

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We used pure porous copper disc as a specimen for small billet forming, and have investigated its formability in the viewpoint of billet height. FEM analysis was also carried out to estimate the characteristics of this process.

## 2. EXPERIMENTAL PROCEDURES

### *2.1 Processing of pure Cu porous disc*

Pure Cu porous disc has been prepared as a specimen for small billet forming experiment. Specimen was made by powder metallurgy technique. Simplified powder forming method which had been suggested by the author [4] was used for making porous sintered disc specimen. The method, which is non-pressurizing forming process, uses agar as binder to solidify metal powder as porous green object without pressurizing. Density of this solidified green object is almost same as apparent density of its raw metal powder. Therefore the relative density of specimen after sintering keeps still low level, thus the porous sintered metal was easily obtained. Schematic view of this simplified powder forming method is shown in Fig. 1. The proposed process proceeds as follows; (1) Agar powder is dissolved into hot water. The amount of agar is 1.0 wt.%. (2) Metal powders are added to the solution. A ratio of powder and water is 67:33 by weight. As a result, powder-slurry is obtained. (3) The powder-slurry is simply casted into a suitable mold without pressurizing. (4) The solidified powder is obtained as an object after cooling, removing from the mold, and drying.

Pure copper powder CE-15 (Fukuda metal foil & powder co, ltd.), where the mean particle size is 70 micro meters, apparent density is 0.17 in density ratio, was used as raw powder. Note that the density ratio is expressed in true density divided by density of sintered specimen. Fig. 2 shows the time – temperature diagram for sintering. As a result, 0.4 ~ 0.6 density ratio has been obtained after sintering.

Since Cu powder – ager slurry solidified object can slice by thin cutter such as a razor blade before drying, it is able to form several number of disc shaped specimens for the desired thickness by one processing. In the experiment, we prepared disc shaped specimen which is 10mm in diameter and 2 or 3 mm in thickness, by cutting solidified porous billet before drying and sintering. Density ratio of the disc specimens after sintering was adjusted at 0.5 (it means that 50% porosity inside). Fig. 3 shows photograph of the sintered specimen with its surface appearance. It is found that many pores were distributed uniformly and it can be used for suggested small billet forming.

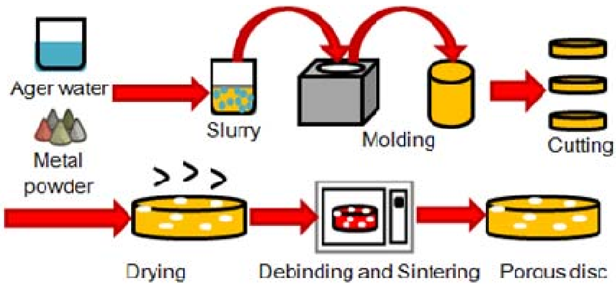



**Fig. 1.** Processing of pure Cu porous disc.

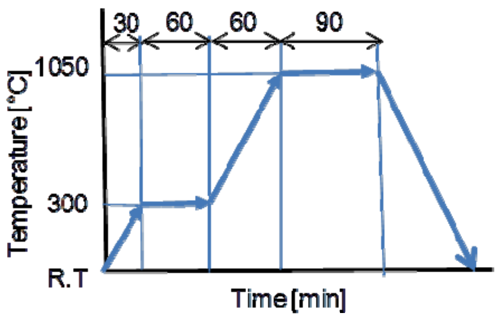



**Fig. 2.** Time-temperature diagram for sintering.

(a) General view (b) Microscopic view

**Fig. 3.** Fabricated porous disc (density ratio=0.5).

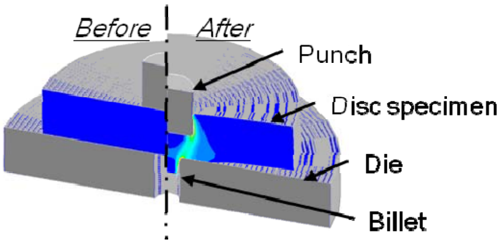



**Fig. 4.** Schematic sectional view of small billet forming illustrated as a result of FEM analysis.

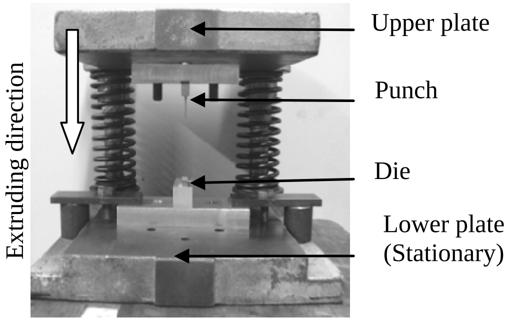



**Fig. 5.** Photograph of the die-set.

### *2.2 Small billet forming experiment*

Fig. 4 shows schematic sectional view of small billet forming. Specimen is placed freely and extruded into die cavity as the punch is indented on the surface, and small billet is formed at reverse face. Diameter of the punch and die cavity is 2.0mm and 1.0mm respectively so that the extrusion ratio is 4. Allowable load is limited at 3000N by strength of the punch.

Fig. 5 shows a photograph of the die-set. The die-set was installed on universal testing machine (Shimadzu co, ltd. UH500kN, Japan). Indentation force and stroke were logged by data sampling system of the machine. After indentation, extruded billet was observed by microscope and billet height was measured. Reduction in thickness, Re% can be defined as

$$Re = (s/t) \text{ x}100\% \quad (1)$$

where $s$ is indentation stroke [mm] and $t$ is thickness of the disc [mm]. Two kinds of lubrications which are silicone polymer, engine oil have been applied. General pure copper (C1100-O by JIS) was also used as common Von-Mises metal material.

### *2.3 FEM analysis*

In order to discuss the forming characteristics of porous sintered Cu, small billet forming has been simulated by using generic finite element method solvers which are ANSYS® and LUSAS®. ANSYS was used to demonstrate deformation of pure Cu as common Von-Mises material. LUSAS was used to demonstrate deformation of porous sintered Cu as Drucker-Prager yield material tentatively. Drucker-Prager yield criteria is known as applicable for materials which exhibit volumetric plastic straining, *e.g.* concrete, soil and rock. This constitutive model is achieved via a modification to the Von-Mises yield criteria and includes the influence of hydrostatic stress. The general form of the Drucker-Prager yield function is given by

$$F(\underline{\sigma},\kappa) = \alpha I_1 + \sqrt{J_2} - k \tag{2}$$

where $I_1$ is the first stress invariant, $J_2$ is the second deviatoric stress invariant and $\alpha$, $k$ are constants that define the yield surface. This yield surface takes the form of a circular cone such as Fig. 6. Both of $\alpha$ and $k$ can be calculated from internal friction angle and Cohesion which are defined in Mohr-Coulomb yield criteria. The material properties to be used with the Drucker-Prager constitutive model in LUSAS are Young's modulus, Poisson's ratio, Cohesion, Internal friction angle and Slope of cohesion with incremental strain [5]. These parameters except for Slope of cohesion were identified from some literatures [6], [7]. The slope of cohesion of specimen has been approximately estimated via simple compression test.

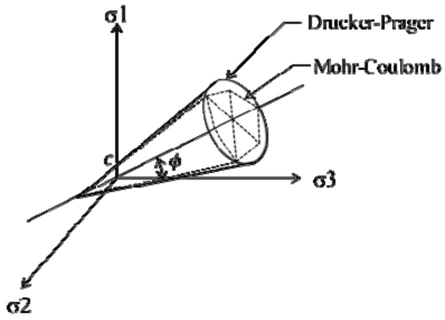



**Fig. 6.** Drucker-Prager yield surface illustrated in principal stress axis.

*2.4 Identification of the slope of cohesion with incremental strain*

In order to obtain value of cohesion, simple compression test for cylindrical specimen have been conducted. We assumed that the slope of cohesion increases linearly with incremental strain. Since the value of cohesion corresponds to shear yield stress when density ratio reached at 1.0 which means full density, we also assumed linear relationship between density ratio and value of cohesion in incremental strain by simple compression. By those considerations, slope of cohesion $\Delta c/\Delta\varepsilon$ and initial cohesion c can be calculated as follows;

$$\frac{\Delta c}{\Delta \varepsilon} = \frac{c|_{\rho=1.0} - c'}{\varepsilon|_{\rho=1.0} - \varepsilon'} \tag{3}$$

$$c = c|_{\rho=1.0} - \frac{\Delta c}{\Delta \varepsilon}\, \varepsilon|_{\rho=1.0} \tag{4}$$

where $\varepsilon$ is strain, $c'$ is value of cohesion corresponds to $\varepsilon'$ which are obtained by simple compression test. The index "$\rho = 1.0$" means full density value. These assumptions can be indicated as Fig. 7. Table. 1 shows the estimated material properties of porous sintered Cu in 0.5 density ratio as input data for Drucker-Prager constitutive model in LUSAS.

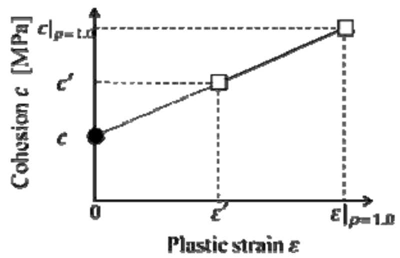



**Fig. 7.** Estimation of the slope of cohesion with intermediate strain which is measured by simple compression test.

**Table 1:** Estimated material properties of porous sintered Cu as an input data for LUSAS

| Powder | Density ratio ? | Young's modulus *E* [GPa] | Poisson's ratio | Cohesion | | Initial friction angle *f* [° ] |
|---|---|---|---|---|---|---|
| | | | | *c* [MPa] | *? c/? e* [MPa] | |
| Cu | 0.5 | 14.9 | 0.27 | 10.2 | 4.87 | 24.5 |

## 3. Results and Discussions

### *3.1 Relations between punch force and reduction in thickness with extruded billet height*

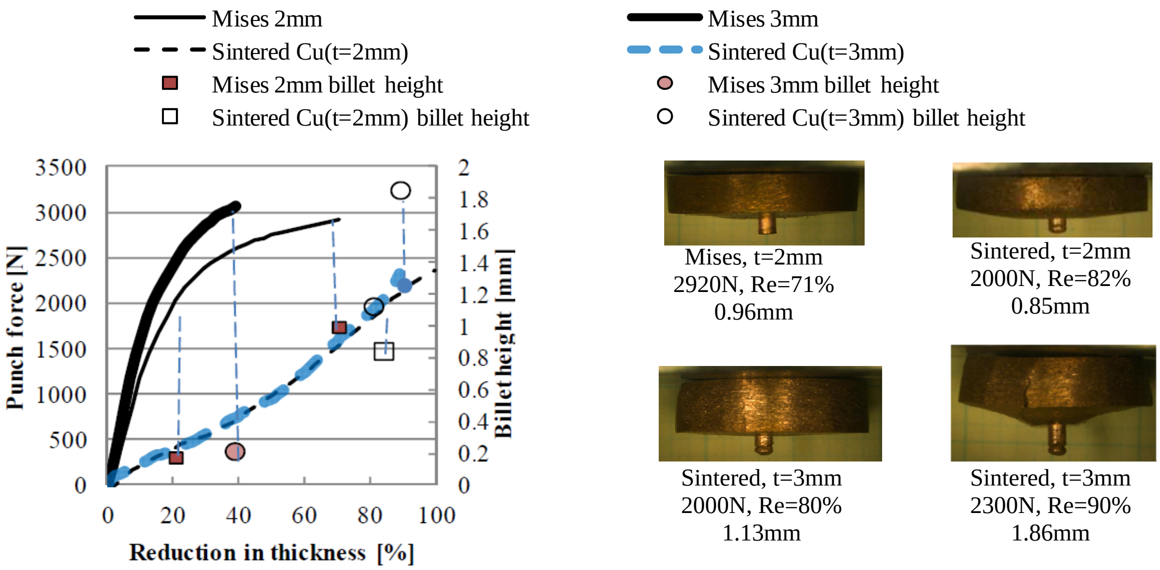



**Fig. 8.** Relations between punch force and reduction in thickness with extruded billet height (Silicone polymer lubrication).

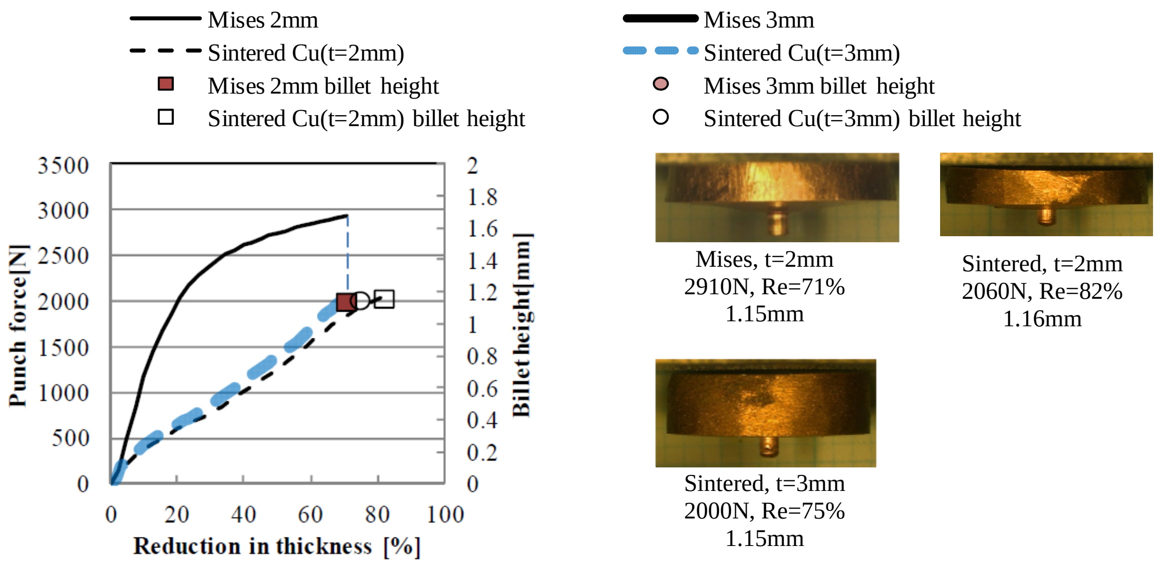



**Fig. 9.** Relations between punch force and reduction in thickness with extruded billet height (Engine oil lubrication).

Fig. 8 and Fig. 9 show that relations between punch force and reduction in thickness. Extruded billet height corresponding with *Re*% is also mentioned by second axis as the symbols. Moreover the photographs of each specimen are also shown. Fig. 8 is the case of silicone polymer lubrication. Continuous line and broken line indicates general pure Cu (mentioned as Mises) and sintered porous Cu respectively. The results clearly demonstrate that the punch force decreases significantly in case of porous material. In case of general Cu, *t*=2mm, 0.96mm billet height was observed at 2920N punch force which results 71% reduction in thickness. In case of porous Cu, *t*=2mm, only 2000N was loaded to achieve 82% reduction which results in 0.85mm height. It is 11% shorter than the case of general Cu in spite of higher reduction in thickness. It is suggested that the effect of volumetric shrinkage appears due to low density. In the case of *t*=3mm, 1.13mm billet height has been obtained in almost same punch force and *Re*%. With increasing the *Re*%, billet height becomes longer but specimen was fractured at *Re*>90% since high circumferential stress occurs at the side of the disc because the disc is not restricted in the radial direction. Thus since the porous Cu shows about 33% lower punch force, thicker disc specimen can be applied for billet forming. As a result, longer billet height can be extruded because of its higher *Re*% in thickness with a little punch force increasing.

Figure 9 shows the case of engine oil lubrication. The almost same tendency as the case of silicone polymer lubrication has been observed but the extruded billet height became little bit longer when using *t*=2mm specimens. It indicates that the ability of the lubricant becomes important but further examination will be demanded to make clear the role of lubrication in proposed billet forming.

These results demonstrate that thicker porous specimen can be applied to such thin punch indentation, so that comparatively large deformation is achieved by using porous metal.
However, as shown in the photograph of the porous specimens, it was seemed that the micro crack occurred at the top of the extruded billet. As regards to the hydrostatic stress distribution calculated by ANSYS as shown in Fig. 10, the top of the billet shows the boundary of compressive stress state and tensile stress state. It is well known that the porous material is quite weak at the tensile stress, thus the micro crack occurs in such small billet forming. It will be effective to apply certain amount of back pressure and restriction of the specimen to avoid the crack occurrence of the process

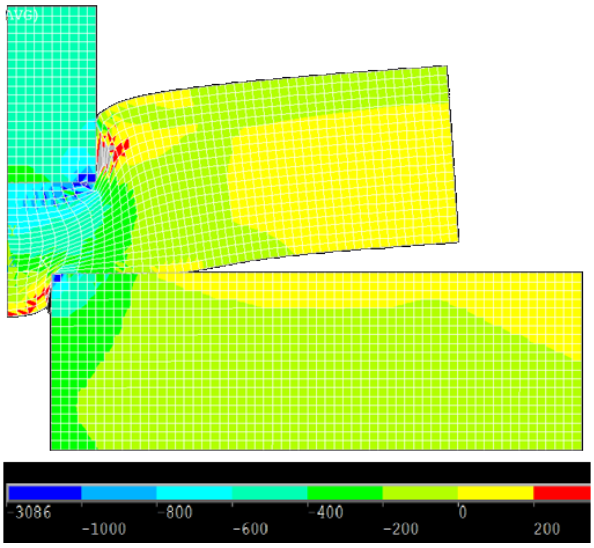



**Fig. 10.** Hydrostatic stress distribution in small billet forming for general Cu material.

*3.2 Distribution of equivalent strain in the small billet forming by FEM analysis*

It has been realized that the billet height of porous Cu is slightly decreased in comparison with the general Cu due to the volumetric shrinkage, but the punch force can be reduced significantly and comparatively longer billet height can be obtain. It suggests that the deformation characteristics of porous material are adequate with the proposed forming process. Relation between punch force and Re% which is calculated tentatively by Drucker-Pragar model in LUSAS is shown in Fig. 11. Unfortunately the analysis was stopped at 0.4mm stroke due to some restrictions such as large mesh deformation at die shoulder. However the result of analysis approximately accorded with the experimental data. Therefore application of Drucker-Prager model will be relevant to predict forming properties of porous material for proposed forming process.

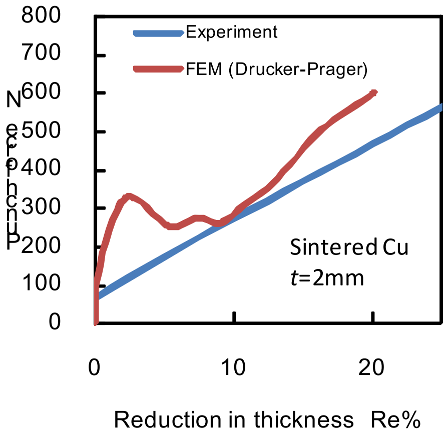
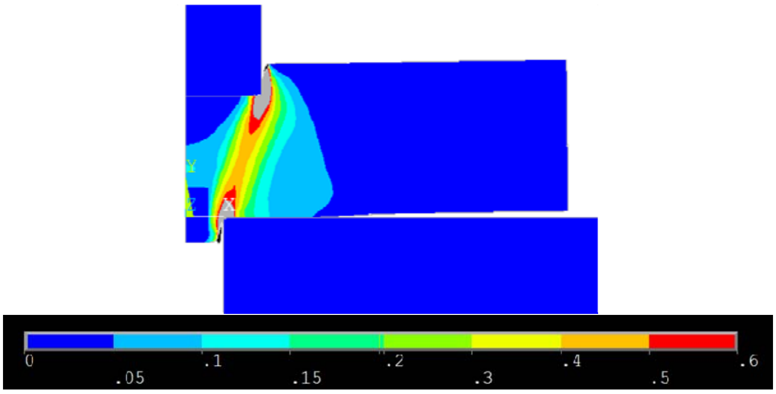
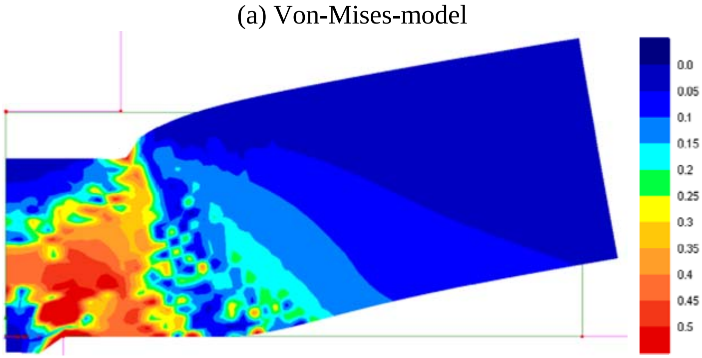



**Fig. 11.** Relation between punch force and Re% of Drucker-Pragar model.

Figure 12 shows the comparison of the distribution of equivalent strain in Von-MIses model and Drucker-Prager model at the same punch stroke. The Von-Mises model shows extreme concentration of the strain from the edge of the punch to the die shoulder. In contrast the strain of the Drucker-Prager model exists in a broad spectrum of deformation area. It is expected that this particular tendency promotes plastic flow below the punch in the direction of indentation.




(a) Von-Mises-model




(b) Drucker-Prager model

**Fig. 12.** Distribution of equivalent strain in the small billet forming by FEM analysis.

## 4. Conclusions

Small billet forming of porous sintered copper has been carried out. We used 50% porous pure copper disc as a specimen. The specimen was placed freely and extruded into die cavity of 1.0mm diameter as the punch was indented on the surface, and small billet was formed at reverse face. The formability of the porous Cu has been investigated as a viewpoint of billet height. The results are summarized as follows:

(1) Indentation punch force is very low in case of porous Cu. It is about 33% lower than the general pure Cu material.
(2) Extruded billet height of porous Cu is 11% shorter in comparison with the general Cu at the same indentation stroke.
(3) Thicker disc can be applied by using porous Cu. As a result, longer billet height can be extruded because of its higher Re% in thickness with a little punch force increasing.

It is concluded that the porous Cu is useful to forming a small or micro billet for miniaturizing forging process because it shows significant low punch force and certain amount of billet height comparing with general Cu material. Micro crack occurred at the top of the billet due to tensile hydrostatic stress state. It will be effective to apply certain amount of back pressure to avoid crack occurrence in the process.

## 5. Acknowledgment

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## References

[1] Hirota, K. and Sugioka, T. Forming of small billet by sheet extrusion, Transactions of the Japan Society of Mechanical Engineers, Series C, Vol. 73(728), 2007, pp. 1253-1258. (*in Japanese*)
[2] Geier, M., Kleiner, M., Eckstein, R., Tiesler, N. and Engel, U. Microforming, Annals of the CIRP, 50/2, pp. 445-462, 2001.
[3] Hakamada, M. and Mabuchi, M. Fabrication by spacer method and evaluation of porous metals, Journal of The Japan Institute of Light Metals, Vol. 62(8), 2012, pp. 313-321. (*in Japanese*)
[4] Taniguchi, Y., Ozaki, M., Kodama, K. and Nakajima, K. Suggestion of simplified powder metallurgy method for engineering education, paper presented in 6th International Symposium on Advances in Technology Education 2012, Kitakyushu, Japan, 2012.
[5] LUSAS, Theory Manual, Vol. 1, LUSAS Version 14.5, No. 1, pp. 175-181.
[6] Khoei, A.R. Numerical simulation of powder compaction processes using an inelastic finite element analysis, Material and Design, Vol. 23, 2002, pp. 526-529.
[7] Tszeng, T.C. and Wu, W.T. A study of the coefficients in yield functions modeling metal powder deformation, Acta Materialia, Vol. 44(9), 1995, pp. 3543-3552.