Prevention of seizure in inner spline backward extrusion by low-cycle oscillation using servo press

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Abstract

To substitute liquid lubricants for phosphate-conversion coating in backward extrusion having severe deformation, a low-cycle oscillation backward extrusion process of a cup having inner splines using a servo press was developed. Seizure in the inside of the forged splines was prevented by low-cycle oscillation. Gaps between the punch land and the spline were caused in each release of oscillation by the difference in elastic recovery between a punch and a formed spline, and the liquid lubricant is automatically fed into a cavity under the punch through the generated gap. The effect of the oscillation on occurrence of the seizure and behaviour of the re-lubrication were investigated. In addition, the oscillated slide motion was optimised to reduce the forming time.

Keywords: Forging; Oscillation; Friction; Lubrication; Seizure; Gallng; Servo press; Phosphate-conversion coating

1. Introduction

A phosphate-conversion coating treatment is commonly used to keep lubrication in cold forging having severe deformation. However, environmental damage by the conversion coating process is large because the discharge of the sludge included heavy metals and large amounts of waste water, and then substitutable lubricants are demanded. Bay et al. (2010) have summarised the environmentally benign lubrication for metal forming. Sagisaka et al. (2012) have developed a double layer type lubricant composed of a high adhesive undercoat and a low frictional overcoat.
and it lubricant is treated by dipping and drying. Arentoft et al. (2009) have developed the lubrication structure which has a porous layer for entrapping lubricant by an electrochemical deposition process.

Recently developed mechanical presses driven by servo motors have a flexible ram motion. Osakada et al. (2011) have reviewed application of mechanical servo presses to metal forming processes. Mori (2011) has demonstrated the effectiveness in utilisation of mechanical servo presses for sheet metal forming processes. Maeno et al. (2014) have improved the drawability in the hot stamping by high speed forming using the servo press.

Although a lot of approaches to maintain the performance of the lubricant applied before forging have investigated, an approach of re-lubrication the workpiece and tools during forming is also effective. Tamai et al. (2010) have improved the formability of high strength steel sheets by detaching tools from the sheet during the deep drawing using the servo press. The sheet was automatically re-lubricated by the detachment. Matsumoto et al. (2011) prevented seizure in backward extrusion by automatically feeding a lubricant using a pulsating ram motion of a servo press with punch having channel for feeding of lubricant. On the other hand, Maeno et al. (2011) developed an automatic re-lubrication approach using load pulsation of a servo press to reduce the force in plate forging. In this approach, a lubricant is automatically fed into a small gap between a plate and die caused by the difference of elastic recovery during load releasing. Furthermore, Maeno et al. (2014) have improved the dimension accuracy in the plate forging of stainless steel parts by the load pulsation. Although the automatic re-lubrication in load pulsation successfully functions for plate forging even a small quantity of lubricant since the surface expansion is comparatively small, larger feeding of the lubricant is required for severe forging such as backward extrusion.

In the present study, inner spline backward extrusion by low-cycle oscillation using servo press was developed. The effect of the oscillated slide motion on the occurrence of the seizure on the tools and formed splines was examined. In addition, the oscillated slide motion was optimised to reduce the forming time.

2. Inner spline backward extrusion by low-cycle oscillation using servo press

An automatic re-lubrication mechanism by low-cycle oscillation in an inner spline backward extrusion is shown in Fig. 1. In Fig. 1 (1) for downstroke of the punch, the gap between the punch-land and formed spline is hardly open, and the elastic deformation of the punch in a groove portion becomes larger than spur portion due to the small reaction force in radial direction from the billet. During the upstroke of the punch (See Fig. 1(2)), the compression force of the punch was released and elastic recovery was occurred. The punch detaches from the inner splines of the billet due to the difference in elastic recovery between the groove portion and the spur portion, and then gaps appear. In addition, the negative pressure is generated in a cavity under the punch, and then the liquid lubricant is automatically fed into the cavity through the gaps.

The tools used for the experiment of the inner spline backward extrusion and mechanical properties of the tools and billet are shown in Fig. 2 and Table 1, respectively. An annealed mild steel S10C cylindrical billet was forged into a cup having 6 inner splines by backward extrusion. The punch and die were made of heat treated high speed steel SKH51 and tool steel SK3 respectively. The lubricants were sulphur additive contained oil-based (Nihon Kohsakuyu Co. Ltd., CF-870), and low and high viscosity types were used. The flow stress curve of the annealed mild steel billet obtained from a compression test is shown in Fig. 3. This flow stress curve was used to the finite element simulation.

The slide motion curves and parameters with and without the oscillation used for the inner spline backward extrusion by the low-cycle oscillation are illustrated in Fig. 4 and Table 2, respectively. For without the oscillation, the crank motion having 23 mm/s in slide speed was employed. On the other hand for with the oscillation, the load was released at equal intervals in stroke in \( n \) times, i.e. the amount of one interval was the total stroke divided by

| Material           | Vickers [HV] | Surface roughness [\( \mu mRa \)] |
|--------------------|--------------|----------------------------------|
| Billet             | Annealed mild steel: S10C | 103                              |
| Punch              | High speed steel: SKH51   | 856                              |
| Die                | Tool steel: SK3           | 675                              |
| Lubricant          | Sulphur additive contained oil-based: low viscosity: \( \nu = 132 \text{ mm}^2/\text{s} \), high viscosity: \( \nu = 556 \text{ mm}^2/\text{s} \) |
To generate the negative pressure to feed the lubricant, the punch goes up after load releasing. When the upstroke of the slide is 1.2 mm, 0.3 mm in height of the cavity was occurred because the elastic deformation of the press and tools. For the oscillation with holding, to improve the re-lubrication by oscillation, the slide during upstroke was stopped in \( t \) seconds. The number of releases and the slide holding time were \( n = 4 – 19 \), \( t = 0 – 1 \) s respectively. 1500 kN CNC servo press (Amada Co. Ltd., SDE-1522) was used for the experiment and the total amount of the punch stroke from contact with the billet is 12 mm.

The deformation behaviour of the punch during downstroke and upstroke was investigated from the finite element simulation. In the simulation, the commercial FEM software DEFORM was used, and the flow stress curve of the mild steel billet as shown in Fig. 3 and mechanical properties of tools as shown in Table 1 were used. The Coulomb friction was assumed and the coefficient of friction was determined to be 0.12 to equalise the calculated load with the experimental one for without the oscillation. To reduce the computational time, only a quarter of the geometry is modelled in three dimensions. Gaps between the punch-land and the formed spline were caused in load release of oscillation obtained from calculation is shown in Fig. 5. The gaps were increased by elastic recovery of the punch, and the gap in the groove portion of the punch is larger than spur portion.
Coulomb friction: \( \mu = 0.12 \)
Punch and die:
- Elastic, \( E = 207 \) [GPa]
- Poisson's ratio \( \nu = 0.3 \)
Billet
- Elastic plastic
- \( E = 200 \) [GPa]
- \( \sigma = 649.8 e^{0.2s} \) [MPa]

3. Prevention of seizure by slide motion having low-cycle oscillation

The variations in forging load with the stroke in the inner spline backward extrusion with and without the oscillation for the low viscosity lubricant are shown in Fig. 6. The forging loads of \( n = 19, t = 0 \) s and \( n = 19, t = 0.5 \) s are decreased compared with without the oscillation in a steady state after \( s = 5 \) mm. However, the difference of the forging load with and without the oscillation is comparatively smaller than the result of the compression of plate (Maeno et al., 2011) and plate forging (Maeno et al., 2014), because the frictional force is considerably smaller than the compressive force of the billet. And the forging load of with and without holding for with the oscillation are almost equal.

The cross-sections of the forged inner spline cup with and without the oscillation for low viscosity lubricant are shown in Fig. 8. The shapes of the formed spline cups are almost same. On the other hand, the inner surface of the formed spline, the remarkable seizure was occurred for without the oscillation, whereas for the oscillation the patterns corresponded with the oscillation were appeared.

Surfaces of the punch-land and bottom-land of formed spline with and without the oscillation for the low viscosity lubricants are shown in Fig. 8. For without the oscillation, not only the remarkable seizure on the punch-land but also the crack caused by seizure is occurred. For with the oscillation, although the seizures were reduced by the re-lubrication of oscillation, seizure has not prevented completely.

The surface roughness of the punch-land and the bottom-land of formed splines with and without the oscillation for the low and high viscosity lubricants were shown in Fig. 9. For with the oscillation, the surface roughness for high viscosity is smaller than that for the low viscosity.
4. Improvement of re-lubrication function by slide holding during upstroke of punch

To feed the lubricant sufficiently, the slide after upstroke is stopped, and then the lubricant is drawn into the cavity under the punch by negative pressure. Surfaces of the punch-land and the bottom-land of the formed splines with the oscillation and with slide holding time for low viscosity lubricant are shown in Fig. 10. The seizure of the punch-land and bottom-land of the formed spline were reduced by slide holding and were completely prevented above $t = 0.5$ s. In addition oil pits were appeared on the surface of the formed spline i.e. fed lubricant by Automatic re-lubrication of the oscillation is sufficient.

The surface roughness of the punch-land and the bottom-land of the formed splines with the oscillation and with slide holding for the low and high viscosity lubricants are shown in Fig.11. The surface roughness is remarkably reduced by slide holding of the oscillation compared with without slide holding as shown in Fig. 9. In addition, the surface roughness for low viscosity lubricant smaller than that for the high viscosity lubricant, and it is contrary to result for without slide holding. Although the high viscosity lubricant is effective to prevent breakage of the oil film in insufficient re-lubrication, the resistance of a fluid to flow to through the gap between punch-land and formed spline is large. The low viscosity lubricant having high fluidity is easily fed into the cavity under the punch, and is suitable for the low-cycle oscillation backward extrusion.
The effect of the slide holding time and the number of releasing of the oscillation on the prevention of seizure of the punch-land and formed splines for the low viscosity lubricant is shown in Fig. 12. The number of releasing without seizure was decreased by slide holding time, and the forging time was reduced.

![Fig. 11. Surface roughness of punch-land and bottom-land of formed splines with oscillation and with slide holding.](image)

![Fig. 12. Effect of slide holding time and number of releasing of oscillation on prevention of seizure for low viscosity lubricant.](image)

5. Conclusion

Environmental safety is more and more important in forging industry, and the phosphate-conversion coating process is a big problem. Inner spline backward extrusion by low-cycle oscillation using a servo press is effective for eliminating the phosphate-conversion coating process. In the present study, an inner spline backward extrusion by low-cycle oscillation using servo press was developed, and the effect of the oscillated slide motion on the occurrence of the seizure on the tools and formed splines was examined. The seizure of the tool and formed splines was prevented by oscillated slide motion having slide holding even in using the oil based lubricant without phosphate-conversion coating. Although for the sufficient the re-lubrication large amount of the lubricant is required in forging having large surface expansion, it attained by the slide holding after upstroke and lubricant having modest viscosity. Since no additional equipment is required, a lubrication system which having re-lubrication by slide oscillation during forming process is not only attractive but also practicable solution as the substitution of the phosphate-conversion coating.

References

Arentoft, M., Bay, N., Tang, P.T., Jensen, J.D., 2009. A new lubricant carrier for metal forming. CIRP Annals – Manufacturing Technology 58 (1), 243–246.

Bay, N., Azushima, A., Groche, P., Ishibashi, I., Merklein, M., Morishita, M., Nakamura, T., Schmid, S., Yoshiida, M., 2010. Environmentally benign tribo-systems for metal forming. CIRP Annals – Manufacturing Technology 59 (2), 760–780.

Maeno, T., Mori, K., Hori, A., 2014. Application of load pulsation using servo press to plate forging of stainless steel parts, Journal of Materials Processing Technology, 214 (7), 1379–1387.

Maeno, T., Mori, K., Nagai, T., 2014. Improvement in formability by control of temperature in hot stamping of ultra-high strength steel parts. CIRP Annals – Manufacturing Technology, doi: http://dx.doi.org/10.1016/j.cirp.2014.03.005

Maeno, T., Osakada, K., Mori, K., 2011. Reduction of friction in compression of plates by load pulsation. International Journal of Machine Tools & Manufacturing 51 (7–8), 612–617.

Matsumoto, R., Sawa, S., Utsunomiya, H., Osakada, K., 2011. Prevention of galling in forming of deep hole with retreat and advance pulse ram motion on servo press. CIRP Annals – Manufacturing Technology 60 (1), 315–318.

Mori, K., 2011. Application of servo presses to sheet metal forming. Key Engineering Materials 473, 27–36.

Osakada, K., Mori, K., Altan, T., Groche, P., 2011. Mechanical servo press technology for metal forming. CIRP Annals – Manufacturing Technology 60 (2), 651–672.

Sagisaka, Y., Ishibashi, I., Nakamura, T., Sekizawa, M., Sumioka, Y., Kawano, M., 2012. Evaluation of environmentally friendly lubricants for cold forging. Journal of Materials Processing Technology 212 (9), 1869–1874.

Tamai, Y., Yamashita, Y., Yoshitake, A., Imura, T., 2010. Improvement of formability in stamping of steel sheets by motion control of servo press, Steel Research International 41 (9), Supplement Metal Forging 2010, 686–689.