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AKAPIT

COMPUTER METHODS IN MATERIALS SCIENCE
Informatyka w Technologii Materiałów

Vol. 7, 2007, No. 2

INFLUENCE OF FORGING PARAMETERS ON TOOL TEMPERATURE IN HOT FORGING

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Abstract

The evaluation of the temperature distribution in the tool surface layer has been strongly required to enable the accurate prediction of the tool life in tool design. The variation in the maximum temperature of a forging tool during hot forging was examined with respect to friction shear factor m, chamfer angle θ, corner radius R and contact time tc, by finite-element analysis. Friction shear factor m greatly influenced the variation in the maximum temperature. In particular, the temperature rise at 80% reduction in area was considerable at m = 0.0-0.2. When the reduction in area exceeded approximately 80%, it was necessary to control the shear friction factor to less than 0.3. When the radius of the corner became more than 2 mm, the rise in the maximum temperature was effectively prevented. This effect was more marked when □= 0o than when $\theta = 30^{\circ}$. The maximum temperature of forging tools can be controlled by selecting the friction shear factor (lubrication or surface modification), the chamfer angle and the corner radius appropriately. A guideline for selecting appropriate conditions in forging process design was presented on the basis of the obtained results.

Key words: hot forging, maximum temperature, tool geometry, friction shear factor

1. INTRODUCTION

The demands concerning hot forging tools, such as accuracy improvement and cost reduction, have become more severe in order to achieve precise hot forging processes for manufacturing net-shaped parts and complex shaped parts. In hot forging, large deformation is possible and beneficial effects such as material improvement are expected. Therefore, hot forging is widely used for manufacturing machine parts. In hot closed-die forging, tools are subjected to heavy mechanical loads and elevated temperatures as a result of the contact between the tool and the hot workpiece. The contact conditions of the tool-workpiece interface greatly influence tool temperature, material flow, deterioration of forging tools and tribological characteristics (Carslaw & Jaeger, 1959; Kellow & Bramley, 1969; Lange & Meyer-Molkemper, 1997; Dean & Silva, 1979; Saiki. et al, 2001; Saiki. et al, 1989; Dadras & Wells,1984; Sadhal, 1981; Im, 1984; Saiki et al, 2006; Altan et al, 1982). The forging tool is deformed slightly, and wear and adhesion occur easily in the punch corner where large thermal load and frictional slide are generated and the contact pressure is high. Therefore, maintaining a high accuracy of forged products becomes difficult. The flow stress of the forging tool decreases when the temperature of the forging tool increases, and plastic deformation is easily induced. In order to obtain an effective strategy for the improvement of the tool life, the optimization of the process design, the working conditions and the tool

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conditions on the basis of the evaluation of thermal load applied to the forging tool is required. In this study, the effects of hot forging conditions, including process parameters and tool geometrical parameters, on tool temperature were investigated.

2. TEMPERATURE ANALYSIS

2.1. Analysis conditions

Figure 1 shows the axisymmetrical model used in the finite element analysis for the evaluation of the temperature distribution in backward extrusion. The Gelerkin method was adopted to formulate the finite element program that was developed in our laboratory. Isoparametric elements with quadrangular four nodes were used in the finite element program. The number of the elements was approximately 700 for the punch and 1300 for the workpiece. The thermal analysis was conducted with the forging cycle divided into six stages: i.e., free resting of the workpiece on the lower tool, forging, ejecting, natural cooling, forced cooling (water-mist cooling by spraying), quasi-forced cooling (weaker cooling than forced cooling in duration between forced cooling stage and free resting stage). In the analysis, the effects of friction shear factor m, chamfer angle θ, corner radius R and contact time tc on the maximum temperature were examined. Table 1 shows the analysis conditions. The tool and workpiece materials were assumed to be JIS-SKD61 and JIS-S45C, respectively. The conditions adopted in the thermal analysis were as follows: contact time, tc = 0.05 s, 0.11 s and 0.15 s, which correspond to the tool initial velocities of 500mm/s, 227mm/s and 166mm/s, respectively; forging cycle time tcy = 3.5s; contact thermal conductance Kc =36.1 kW/(m^{2}K); forced-cooling heat-transfer coefficient α_{cool} =2.0 kW/(m^{2}K); cooling time t_{cool} =1.11 s. For simplicity, the average values that were obtained from our thermal model experiments were used as contact thermal conductance and forced-cooling heat-transfer coefficient in this study. An influence of lubricant layer and scale layer was also taken into consideration for the value of thermal contact conductance.

The initial temperatures of the workpiece and the tool base were 1150°C and 150°C, respectively. The tool stroke and chamfer diameter D_{ch} were 25mm and 10 mm, respectively. The boundary conditions used in the analysis region are shown in figure 2. Regions (1)-(4) are the contact boundary, regions (5) and (8) are the convection boundary, region (6) is the temperature boundary, and region (7) is the adiabatic boundary. In the analysis, the contact between punch and workpiece was repeated. An old workpiece was replaced with new one in every contact. The boundary (7) in the bottom and the right of workpiece was not influenced thermally in every contact. Thus, the boundary (7) was assumed as adiabatic boundary.

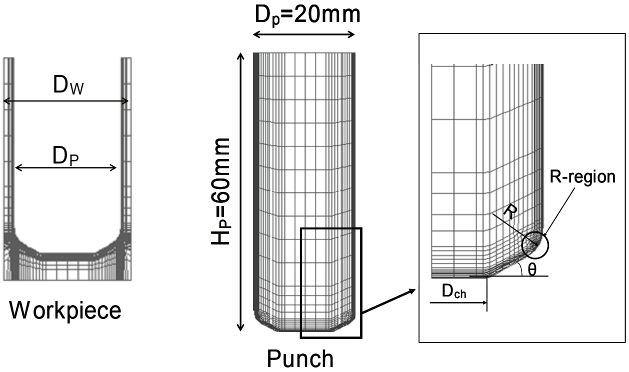


Fig. 1. Analysis model used in the temperature analysis in backward extrusion forging.

Table 1. Analysis conditions.

Tool material	JIS-SKD61
Forging material	JIS-S45C
Initial workpiece temperature (°C)	1150
Tool base temperature (°C)	150
Contact time (s)	0.05, 0.11, 0.15
Forging cycle time (s)	3.5
Cooling time (s)	1.11
Punch stroke (mm)	25

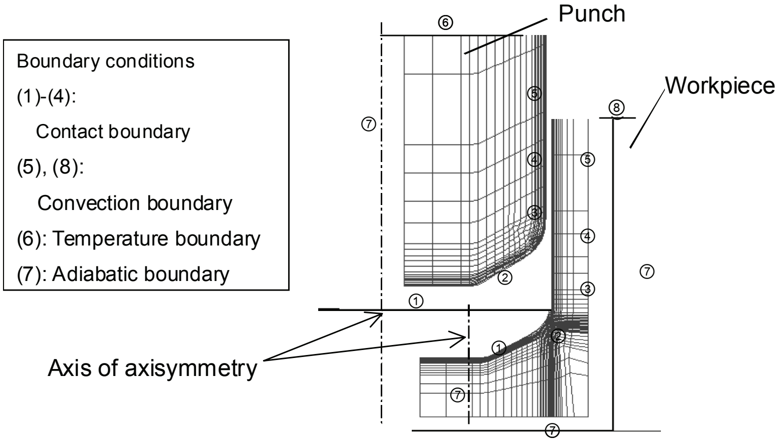


Fig. 2. Boundary conditions in the analysis region.

2.2. Results of analysis

Figure 3 shows the temperature variation at a certain point in the R-region shown in figure 1 during forging cycles. When the forging cycle is repeated up to a certain number of times after the start of forging, the periodical temperature variation of the forging tool reaches a steady variation. Figure 4 shows the periodical temperature variation during one forging cycle under steady variation. The maximum temperature, which occurs in the R-region under the steady temperature variation, was examined regarding friction shear factor m, chamfer angle θ and corner radius R.

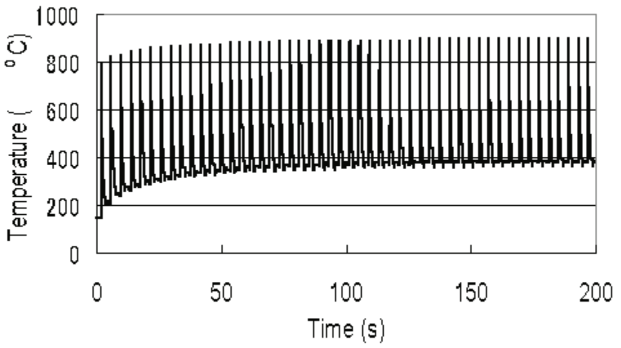


Fig. 3. *Periodical variation in temperature of the forging tool (punch) during forging cycles.*

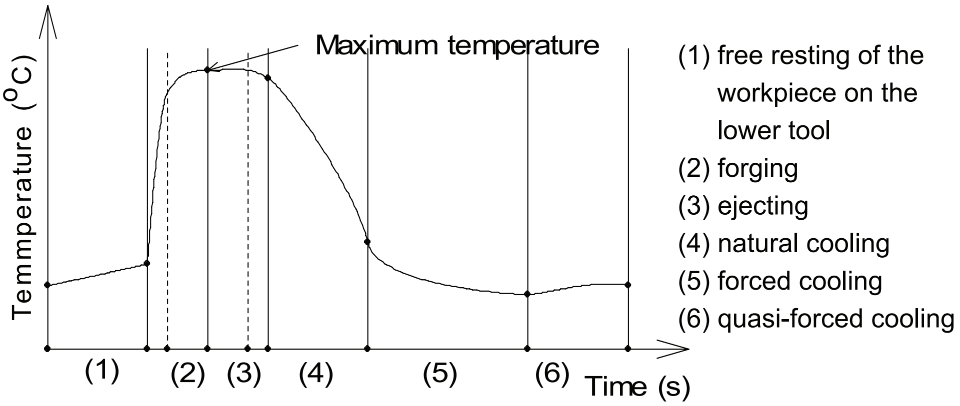
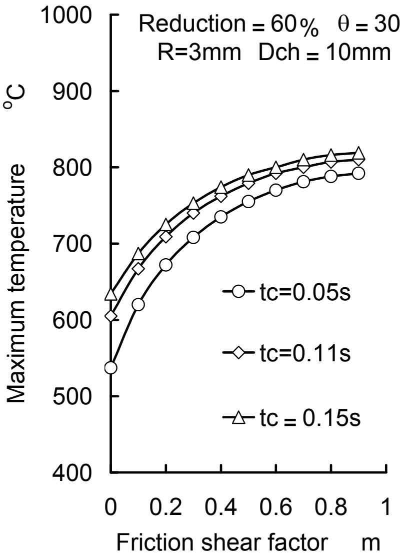


Fig. 4. *Periodical variation in temperature of the forging tool (punch) during one forging cycle under steady temperature variation.*

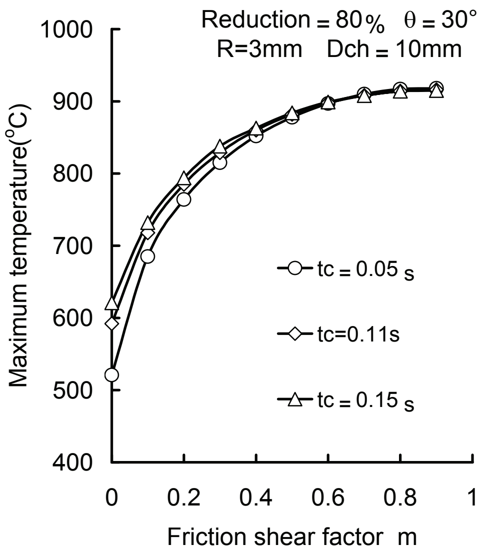
Figure 5 shows the variation in the maximum temperature of the punch with friction shear factor m at 60% and 80% reductions in area. Here, the punch has $D_{ch} = 10$ mm, $R = 3$ mm and $\theta = 30°$; the contact times (duration) are 0.05 s, 0.11 s and 0.15 s. The temperature increases with increasing friction shear factor. The temperature rise at 80% reduction in area is marked in the range of $m = 0.0\text{-}0.2$. It is found that the friction shear factor greatly influences the increase in the maximum temperature. This trend is also seen in the temperature distributions shown in figure 6. When the reduction in area exceeds approximately 80%, it is necessary to control the friction shear factor to less than 0.3. The tendency for the maximum temperature to increase as the contact time becomes long is seen with both 60% and 80% reductions in area. However, with 80% reduction in area, there is no difference in maximum temperature between the three contact times when the friction shear factor exceeds approximately 0.5. With short contact time, frictional heat generation in the punch-workpiece interface more strongly influences the temperature rise.

Figures 7(a) and (b) show the variation in the maximum temperature with corner radius R for $\theta = 0^{\circ}$ and 30° when $D_{ch} = 10$mm, $tc = 0.11$ s and $m = 0.3$. For $\theta = 0^{\circ}$, the maximum temperature increases gradually as the corner radius becomes small, and increases rapidly for all reductions in area when the corner radius becomes less than 2 mm. The thermal influence becomes significant as the radius of the corner becomes small. The similar trend is seen for $\theta = 30^{\circ}$. It is found that the increase in the maximum temperature is effectively prevented by setting the corner radius to be more than 2mm. This effect is more marked when $\theta = 0^{\circ}$ than when $\theta = 30^{\circ}$. When the corner radius is larger than 2 mm, the maximum temperatures when $\theta = 30^{\circ}$ are higher than those when $\theta = 0^{\circ}$. The thermal influence is significant when the chamfer angle is large. Figures 8(a) and (b) show the temperature distributions of punch for $R = 1$ mm and 6 mm. For the small radius $R = 1$mm, the high temperature region concentrates in the corner region.

Figure 9 shows the variation in the maximum temperature with chamfer angle θ when $R = 3$ mm, $D_{ch} = 10$ mm, $tc = 0.11$ s and $m = 0.3$. The maximum temperature increases with increasing chamfer angle. Figure 10 shows the variation in the maximum temperature with contact time. The maximum temperature increases with increasing contact time. Thermal influence also extends from the surface to deeper regions as the contact time becomes longer, as shown in the temperature distributions in figure 11.

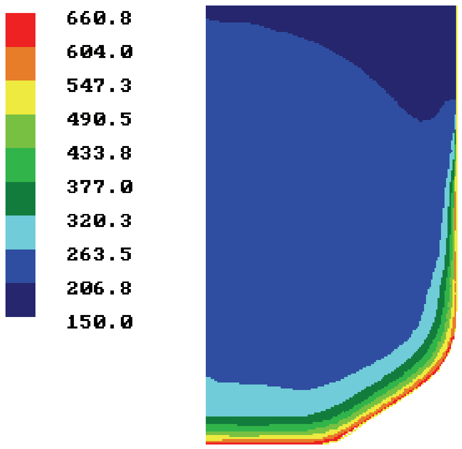


(a) Reduction 60%

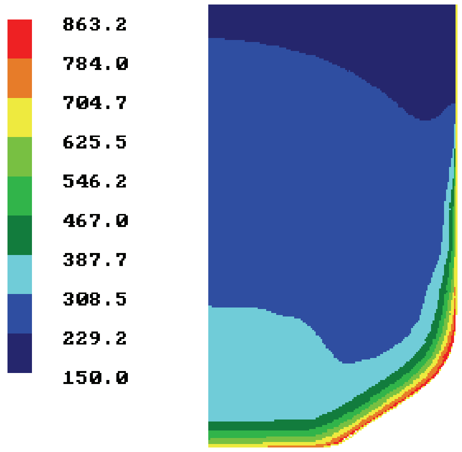


(b) Reduction 80%

Fig. 5. *Variation in maximum temperature of punch with friction shear factor.*

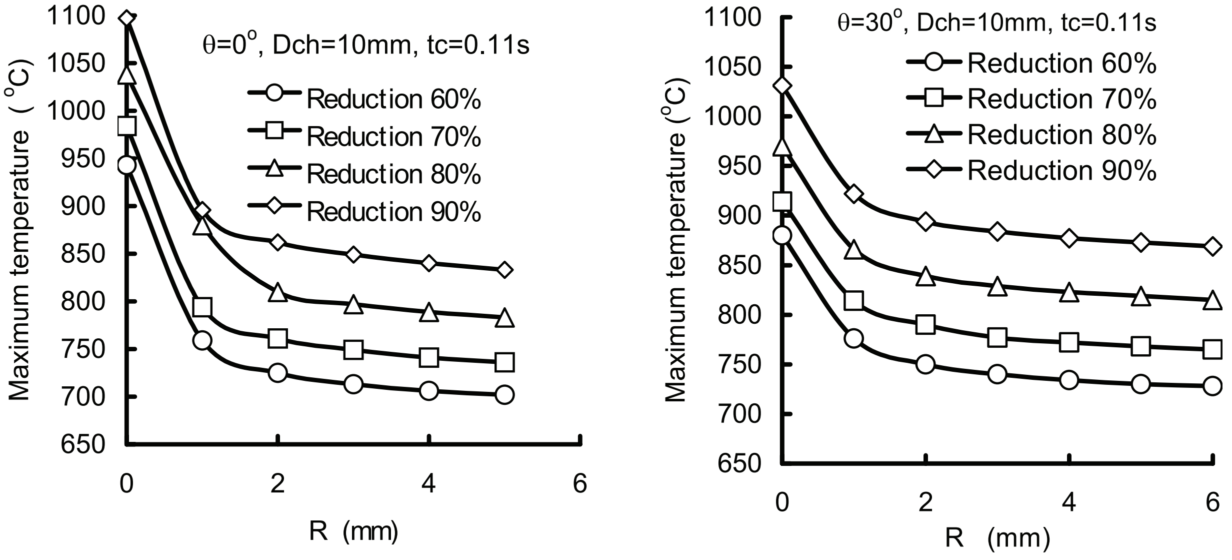


(a) m = 0



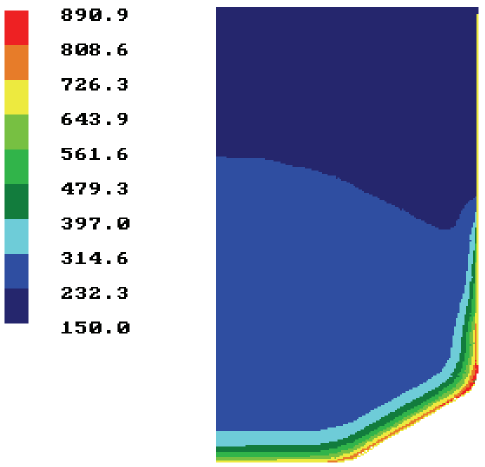
(b) m = 0.6

Fig. 6. *Temperature distributions of punch (θ=30°, R=3mm, reduction=80%, tc=0.15s)*

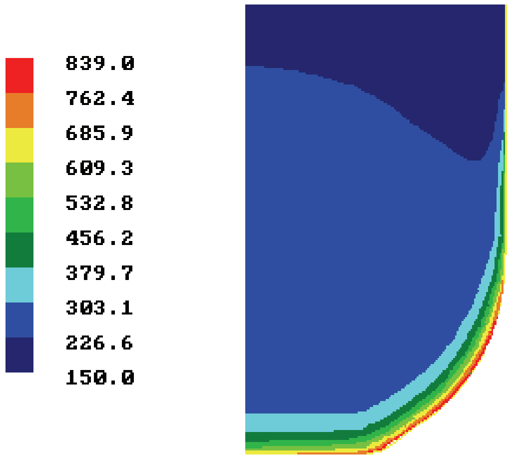


(a) θ = 0° **(b) θ = 30°**

Fig. 7. *Variation in maximum temperature of punch with corner radius R.*



(a) *R* = 1mm



(b) *R* = 6mm

Fig. 8. *Temperature distributions of punch ($\theta = 30^o$, reduction = 90%, tc = 0.11 s).*

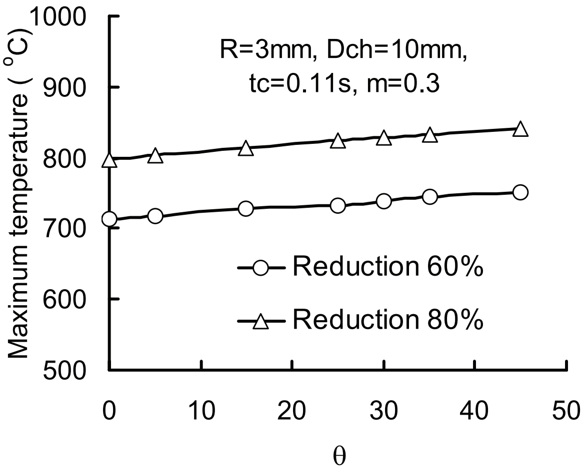


Fig. 9. *Variation in maximum temperature of punch with chamfer angle θ.*

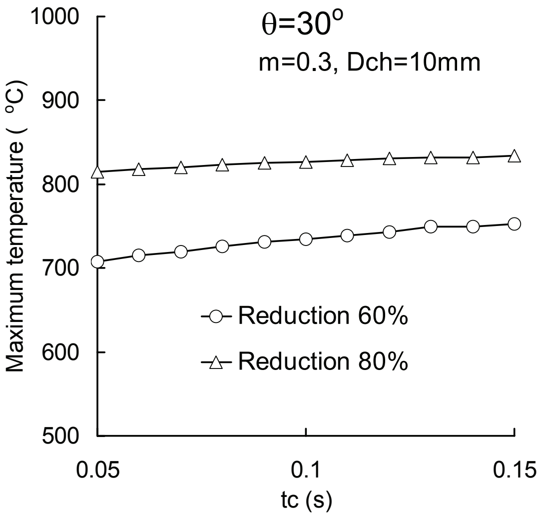
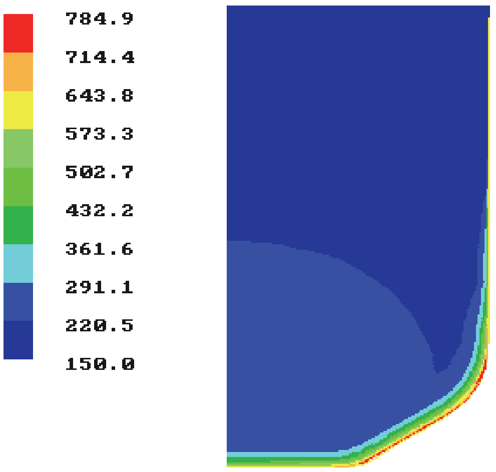
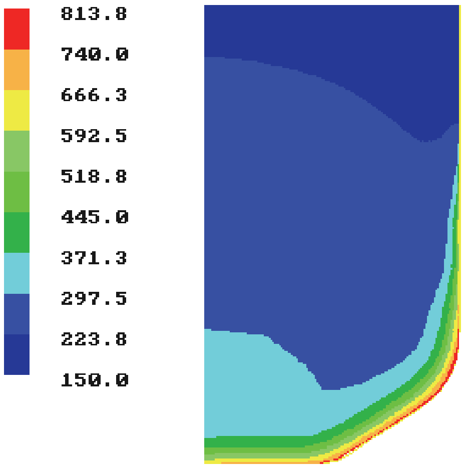


Fig. 10. *Variation in maximum temperature of punch with contact time tc.*



(a) *tc* = 0.05 s



(b) *tc* = 0.15 s

Fig. 11. *Temperature distributions of punch ($\theta = 30^o$, reduction = 80%, R = 3 mm, m = 0.3).*

3. CONCLUSIONS

The variation in the maximum temperature of a forging tool in hot forging was examined with respect to friction shear factor m, chamfer angle θ, corner radius R and contact time tc. The following results were obtained.

1) The temperature increased with increasing friction shear factor. In particular, the temperature rise at 80% reduction in area was considerable in the friction shear factor range of 0-0.2. The friction shear factor greatly influenced the variation in maximum temperature. When the reduction in area exceeds approximately 80%, it will be necessary to control the shear friction factor to less than 0.3.
2) The maximum temperature increased rapidly when the corner radius became less than 2 mm. The thermal influence became significant as the radius of the corner became small. The increase in the maximum temperature can be effectively prevented by setting the corner radius to be more than 2 mm. This effect was more marked when $\theta = 0^{\circ}$ than when $\theta = 30^{\circ}$.
3) When the corner radius was larger than 2 mm, the maximum temperatures when $\theta=30^{\circ}$ were higher than those when $\theta = 0^{\circ}$.
4) The maximum temperature increased with increasing chamfer angle when the corner radius was more than 2 mm.
5) The maximum temperature increased with increasing contact time. Thermal influence also extended from the surface to deeper regions as the contact time become longer.
6) It is expected that the maximum temperature of forging tools can be controlled by selecting the friction shear factor (lubrication or surface modification), the chamfer angle and the corner radius appropriately.

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WPŁYW PARAMETRÓW PROCESU NA TEMPERATURĘ NARZĘDZI PODCZAS PROCESU KUCIA NA GORĄCO

Streszczenie

Analiza rozkładu temperatur na warstwie powierzchniowej rozpatrywanego narzędzia jest niezbędna w celu dokładnego przewidywania cyklu życia narzędzia już w fazie jego projektowania. Za pomocą metody elementów skończonych przeprowadzono badanie odchylenia stempla podczas procesu kucia na gorąco z uwzględnieniem współczynnika tarcia, kąta fazowania, promienia zaokrąglenia naroża oraz czasu styku. Współczynnik tarcia ma bardzo duży wpływ na obliczone odchylenie w temperaturze maksymalnej. W szczególności, gdy wartość gniotu przekraczała w przybliżeniu 80%, konieczne było zmniejszenie współczynnika tarcia do wartości poniżej 0.3. Natomiast podczas gdy promień zaokrąglenia naroża przekraczał 2 mm, wówczas wzrost temperatury maksymalnej był skutecznie hamowany. Efekt ten był zdecydowanie widoczny dla parametru kąta fazowania w zakresie 0°-30°. A zatem maksymalna temperatura stempla może być kontrolowana poprzez wybór odpowiedniego współczynnika tarcia (np.: poprzez smarowanie lub modyfikację powierzchni), kąta fazowania oraz promienia zaokrąglenia naroża. Sposób wyboru tych parametrów przedstawiony został w niniejszym artykule.

Submitted: October 20, 2006
Submitted in a revised form: December 2, 2006
Accepted: December 6, 2006