Mold Wear During Die Forging Based on Variance Analysis and Prediction of Die Life

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Abstract: A process parameter optimization method for mold wear during die forging process is proposed and a mold life prediction method based on polynomial fitting is presented, by combining the variance analysis method in the orthogonal test with the finite element simulation test in the forging process. The process parameters with the greatest influence on the mold wear during the die forging process and the optimal solution of the process parameters to minimize the wear depth of the mold are derived. The hot die forging process is taken as an example, and a mold wear correction model for hot forging processes is derived based on the Archard wear model. Finite element simulation analysis of die wear process in hot die forging based on deform software is performed to study the relationship between the wear depth of the mold working surface and the die forging process parameters during hot forging process. The optimized process parameters suitable for hot forging are derived by orthogonal experimental design and analysis of variance. The average wear amount of the mold during the die forging process is derived by calculating the wear depth of a plurality of key nodes on the mold surface. Mold life for the entire production process is predicted based on average mold wear depth and polynomial fitting.

Key words: die forging process; Deform; analysis of variance; mold wear; die life prediction

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0 Introduction

With the continuous development of the military industry, die forging has a broad application prospect in the aviation industry, and the mold industry has gradually transformed from the traditional market to the emerging high-end market. In the hot forging process, the high-end market also puts forward high precision, short cycle, long life and low cost requirement for mold manufacturing, and the die life has always been a problem that affects actual production efficiency and economic benefits. In the die forging process[1], the die life is mainly affected by die failure. The basic forms of the die failure are: plastic deformation, fatigue fracture, and mold wear. The mold failure caused by mold wear accounts for about 70% of all failure modes, so mold wear[2] becomes the most important factor affecting mold life. Therefore, how to reduce the wear of the mold and improve the life of the mold has become a difficult problem in the die forging industry.

Many scholars have conducted studies on die wear during die forging and related fields. Painter et al.[3] applied finite element numerical simulation method to hot extrusion process. The detailed simulation of the wear process of the mold was carried out. The cavity of the mold was optimized by comparison between simulation and experiments. Lee and Im[4] conducted a study on mold deformation and mold wear by finite element method, considering the influence of temperature and time on the

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wear process, and revised the Archard theoretical model. Lee and Jou[5] applied numerical simulation technology to the wear process of H_{13} steel mold, and measured the wear coefficient through the wear test. It was found that the wear coefficient was positively correlated with temperature. Abachi et al.[6] studied the wear process of hot forging die from the perspective of mechanical stress and temperature, and proposed the performance requirement of the die material in the hot forging process. Eriksen[7] reduced the amount of mold wear by optimizing the mold design. Zhou et al.[8] studied the influence of different process parameters on mold wear in the forging process according to the Archard theoretical model.

Die life has an important impact on the economic cost of the entire die forging process. The study of the relationship between mold wear depth and die forging process parameters[9] based on finite element simulation can save costs. Therefore, the deform software is adopted to analyze finite element simulation results[10] of the whole die forging process.

Aanalysis method is deducted using the Archard wear theory, and a mold wear correction model suitable for hot die forging process is established. By combining the orthogonal test design and the mold wear correction model, the analysis of simulation results is used to study the influence of process parameters on the mold wear. The variance analysis method is used to calculate the influence degree of different die forging process parameters on the mold wear, and the optimal process parameters are found to minimize the die wear depth during die forging. The influence of the amount of mold wear on the life of the mold is investigated via the simulation. From the finite element simulation results, the key nodes with large wear on the mold are found. The average wear depth of the entire mold is obtained by calculating the wear amount of each key node, and then the life of the mold in the die forging process is predicted by the polynomial fitting method[11]. Fig.1 is a flow chart of the analysis on the mold wear in the die forging.

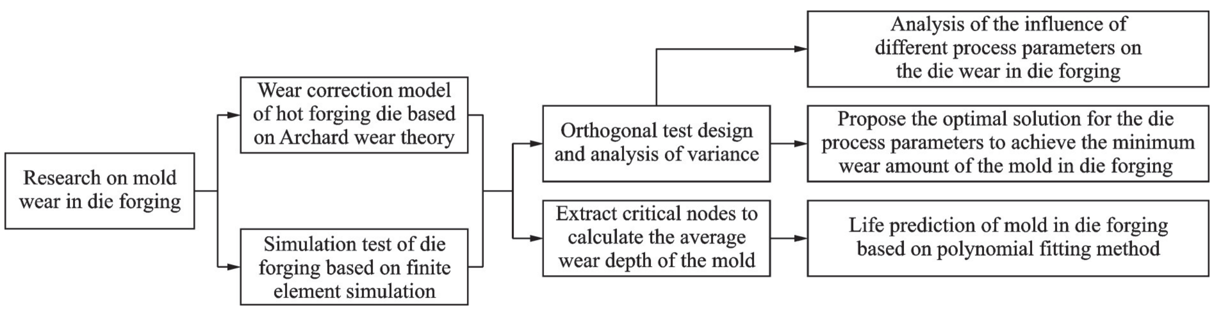

Fig.1 Flow chart of the analysis on mold wear during die forging

1 Establishment of Die Forging Wear Model

When process parameter settings change, the temperature, equivalent stress distribution, metal flow velocity and other results in the die forging process will also change accordingly. Therefore, the setting of process parameters can indirectly affect the wear of the mold.

1.1 Introduction to Archard theory

In actual production, these process parameters can be combined to construct a theoretical model of die forging process parameters and mold wear depth. In the Archard wear model[12], the wear rate can be expressed as a function model as follows

$$\mathrm{d}V = K\frac{\mathrm{d}p\cdot\mathrm{d}l}{H_\mathrm{m}} \tag{1}$$

where V is the wear volume; K the wear coefficient, and for ordinary steel material K is 10^{-2}—10^{-7}; p the normal pressure of the contact surface between the blank and the mold; l the relative displacement between the mold and the blank; and H_m the hardness of the mold.

1.2 Establishing a mold wear correction model

In the hot forging process, the temperature change is related to time, so the wear volume V, the pressure P of the mold, and the relative displacement l between the mold and the blank can be expressed as a function of time

$$\begin{cases} \mathrm{d}V = \mathrm{d}W \cdot \mathrm{d}A \\ \mathrm{d}P = \sigma_n \cdot \mathrm{d}A \\ \mathrm{d}l = v \cdot \mathrm{d}t \end{cases} \tag{2}$$

where W is the amount of mold wear; A the contact area between the blank and the mold; σ_n the stress value of the blank; v the relative slip speed between the blank and the mold, i.e., the deformation speed of the blank; and t the slip time. A modified model of mold wear is derived from Eq.(2).

$$\mathrm{d}W = K \frac{\sigma_n(s,t) \cdot v(s,t)}{H_m(s,t)} \mathrm{d}t \tag{3}$$

where $\mathrm{d}W$ is the wear depth; K the wear coefficient; s the displacement of the mold; and t the time during which the mold moves. Therefore, $\sigma_n(s,t)$, $v(s,t)$, $H_m(s,t)$ are expressed as: The stress value, deformation speed and mold hardness of the mold in a certain position at a certain moment. Eq.(3) is integrated to derive the amount of mold wear at a certain moment in the die forging process.

$$W(s) = K \int_0^t \frac{\sigma_n(s,t) \cdot v(s,t)}{H_m(s,t)} \mathrm{d}t \tag{4}$$

Eq.(4) is numerically simulated to establish a functional[13-14] model between the forging process parameters and the maximum wear depth of the mold.

$$W_{max} = f(v, T, \varepsilon_F, m) \tag{5}$$

where W_{max} is the maximum mold wear amount in the die forging process; v the deformation speed of the blank; T the deformation temperature of the blank; ε_F the deformation degree of the blank; and m the friction factor between the blank and the mold. It can be seen from the mold wear function model that the factors affecting the wear of the mold include deformation speed v, deformation temperature T, deformation degree ε_F, and friction factor m. If the difference in properties of different blank materials and mold materials is neglected, only the influence of process parameters on mold wear is considered. Then the process parameters corresponding to the deformation speed v, the deformation temperature T, and the deformation degree ε_F are the initial temperature of the blank, the initial temperature of the mold, and the strike speed of the upper mold. These three process parameters have higher impacts on the amount of mold wear during hot forging.

Since Eq.(1) does not consider the effect of temperature rise on mold wear during forging, the effect of temperature is introduced into Eq.(1) to obtain a mold wear theory suitable for hot forging processes.

$$W(T) = K(T) \frac{PL}{H(T)} \tag{6}$$

where $W(T)$ is a function of the amount of wear with respect to temperature; $K(T)$ a function of the wear coefficient with respect to temperature; P the mold pressure; L the relative slip distance between the mold and the blank; and $H(T)$ a function of mold hardness with respect to temperature. Introducing the idea of finite element into Eq.(6), we have

$$\Delta W_{ij} = K(T) \frac{P_{ij} L_{ij}}{H(T)} \tag{7}$$

where ΔW_{ij} is the wear depth at the i-node of the mold at the j-moment; P_{ij} the normal pressure at the i-node of the mold at the j-moment; and L_{ij} the relative slip distance of the i-node at the j-moment of the mold. The entire die forging process is simulated by the Deform software, and the total wear depth of the die at the i-node over a period of time can be obtained.

$$W_{ij} = \sum_{j=1}^{n} K(T) \frac{P_{ij} L_{ij}}{H(T)} \tag{8}$$

where W_{ij} is the total wear depth of the mold at the i-node during that time period, and n the total number of steps in the simulation. In this die forging process, the average wear depth of the mold is

$$\overline{w} = \frac{1}{n} \sum w_i \tag{9}$$

where $\overline{w}$ is the average wear amount of the mold; n the total number of nodes extracted from the mold during finite element simulation; and w_i the amount of mold wear on the ith node. With the fixed k and H, the amount of wear of the mold and material contact surfaces during hot forging can be calculated by numerical simulation. So the depth of mold wear during the hot forging process can be calculated by finite element simulation.

2 Application of Orthogonal Test Method

Orthogonal test design[15-16] is a high-efficiency experimental design method for studying multi-factor and multi-level. For the die wear in die forging, the initial temperature of the blank, the initial temperature of the die, and the strike speed of the upper die are controllable objects. According to the die wear correction model for hot die forging, these three key process parameters have a significant impact on the die wear during the die forging process. Therefore, three-factor four-level orthogonal test design is conducted for these three key process parameters.

2.1 Orthogonal test design for die forging process

This experiment uses the orthogonal table of $L_{16}(4^3)$. The initial temperature of the blank, the initial temperature of the mold, and the striking speed of the upper mold are taken as three experimental factors. Four levels of values under each factor are found and a total of 16 experiments are conducted. Deform simulation is used to analyze the amount of mold wear obtained from each set of experimental results, and finally the optimum process parameters for minimizing the wear depth of the mold are derived.

According to the actual production process requirements of this experiment, the initial billet temperature ranges from 900 ℃ to 1200 ℃, the initial mold temperature from 250 ℃ to 400 ℃, and the upper mold striking speed from 300 mm/s to 600 mm/s. The initial billet temperature, initial mold temperature, and upper die striking speed can be divided into four levels according to Table 1. The initial temperatures of the blanks are 900, 1 000, 1 100, and 1 200 ℃. The initial temperatures of the molds are 250, 300, 350, and 400 ℃, and the upper die strike speeds are 300, 400, 500, and 600 mm/s. The factors for the actual die forging process is shown in Table 1.

Table 1 Factors for die forging process

Process parameter	Level			
	1	2	3	4
Initial billet temperature / ℃	900	1 000	1 100	1 200
Initial mold temperature / ℃	250	300	350	400
Upper die strike speed / ($mm \cdot s^{-1}$)	300	400	500	600

A three-factor four-level orthogonal test design is performed according to the factors and levels divided in Table 1. The selected orthogonal table is $L_{16}(4^3)$. The orthogonal test scheme of the mold wear amount based on the die forging process parameters is shown in Table 2.

Table 2 Orthogonal test plan

Experiment number	Billet temperature /℃	Mold temperature / ℃	Strike speed/ ($mm \cdot s^{-1}$)	Die wear depth / μm
1	900	250	300	82.6
2	900	300	400	83.2
3	900	350	500	73.4
4	900	400	600	77.6
5	1 000	250	400	69.2
6	1 000	300	300	64.1
7	1 000	350	600	64.4
8	1 000	400	500	70.8
9	1 100	250	500	58.4
10	1 100	300	600	60.2
11	1 100	350	300	56.4
12	1 100	400	400	62.2
13	1 200	250	600	52.6
14	1 200	300	500	51.6
15	1 200	350	400	54.2
16	1 200	400	300	52.6

To analyze Table 2 more intuitively, we plot the results of Table 2 as a bar chart, as shown in Fig.2. When the test number is 14, the mold wear amount in the die forging has a minimum value of 51.6. Therefore, it can be inferred that when the initial temperature of the blank is 1 200 ℃, the initial temperature of the mold is 300 ℃, and the strike speed of the upper mold is 500 mm/ s. The mold wear depth has a minimum value of 51.6 μm.

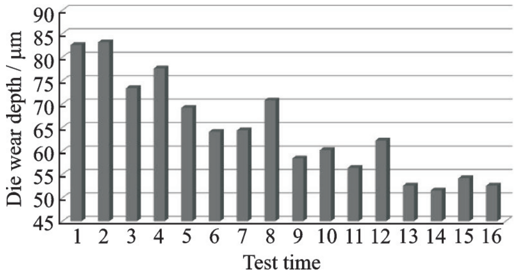

Fig.2 Orthogonal test data strip chart

2.2 Variance analysis

Because of the comprehensive comparability of orthogonal tables, a more scientific analysis of variance[17-18] can be used to analyze the entire test results. According to the analysis of variance, it has

$$\begin{cases} \bar{x} = \dfrac{1}{n}\sum_{i=1}^{m}\sum_{j=1}^{p} x_{ij} \\ S_j = p\sum_{i=1}^{m}(x_i - \bar{x})^2 \\ S_T = \sum_{i=1}^{m}\sum_{j=1}^{p}(x_{ij} - \bar{x})^2 \\ S_e = S_T - \sum_{j=1}^{p} S_j \end{cases} \tag{10}$$

where m is the number of levels; p the number of factors; n the total number of trials; i the level; j the factor; x_{ij} the experimental result of the ith level of the jth factor; $\bar{x}$ the average of all trials; S_j the sum of the squared differences of the jth factor; x_i the test result of the ith level; S_T the sum of the squared differences of all test results; and S_e the sum of the squared differences of the errors. Eq. (10) is mainly used to calculate the difference between each factor and all test results. The influence weight of different factors on the test results is derived by the ratio of the square of the difference to the degree of freedom.

$$\begin{cases} f_T = n - 1 \\ f_j = m - 1 \\ f_e = f_T - f_j \end{cases} \tag{11}$$

where f_T is the total degree of freedom of the test; f_j the degree of freedom of the jth factor; and f_e the degree of freedom of the test error.

$$\begin{cases} \overline{S_j} = \dfrac{S_j}{f_j} \\ \overline{S_e} = \dfrac{S_e}{f_e} \\ F = \dfrac{\overline{S_j}}{\overline{S_e}} \end{cases} \tag{12}$$

where $\overline{S_j}$ is the sum of the mean squared differences of the jth factor; $\overline{S_e}$ the sum of the mean squared differences of the test errors; F the ratio of the two, reflecting the degree of influence of various factors on the test results. The significance of each factor is derived by comparing F with the critical value F_α.

The results of the variance analysis of Table 3 are obtained by analyzing Table 2. From Table 3, F values of the three different factors of billet temperature, mold temperature and striking speed are $F_1=51.715$, $F_2=0.087$, and $F_3=0.089$. When the confidence α is 0.01, $F_\alpha(3, 12)=5.95<F_1$, the difference is statistically significant, so the influence of the billet temperature on the test results is significant. When the confidence α is 0.1, $F_\alpha(3, 12)=2.61>F_3>F_2$, the difference is not statistically significant. Therefore, the influence of the mold temperature and the striking speed on the test results is less significant. The initial billet temperature has the greatest influence on the mold wear in the hot forging process, and the impacts of the upper mold striking speed and initial mold temperature on the mold wear are low.

Table 3 Results of variance analysis

Process parameter	S_j	S_e	f_j	f_e	$\overline{S_j}$	$\overline{S_e}$	F
Billet temperature	1 552.192	120.057	3	12	517.397	10.005	51.715
Mold temperature	35.722	1 636.528	3	12	11.907	136.377	0.087
Strike speed	36.512	1 635.738	3	12	12.171	136.311	0.089

By estimating the marginal mean value of Table 2, we obtain the estimated range of mold wear depth and its average wear amount under different initial billet temperatures, initial mold temperatures, and upper die striking speeds, as shown in Table 4.

Table 4 Range of mold wear depth under different factors

Process parameter	Billet temperature/℃				Mold temperature/℃				Strike speed/(mm•s^{-1})			
	900	1 000	1 100	1 200	250	300	350	400	300	400	500	600
Wear average	79.200	67.125	59.300	52.750	65.700	64.775	62.100	65.800	63.925	67.200	63.550	63.700
Lower wear limit	75.746	63.671	55.846	49.296	62.246	61.321	58.646	62.346	60.471	63.746	60.096	60.246
Upper wear limit	82.654	70.579	62.754	56.204	69.154	68.229	65.554	69.254	67.379	70.654	67.004	67.154

By analyzing Table 4, we can obtain the average wear depth curve of the mold at different billet temperatures, the average wear depth curve of the mold at different mold temperatures, and the average wear depth curve of the mold at different strike speeds. Three sets of test data are processed by quadratic fitting method, and the optimal process parameters for minimizing the wear amount of the mold are obtained according to the range of values of different process parameters.

As shown in Fig.3, the equation of the curve of the billet temperature and mold wear amount is $Y = 1.38 \times 10^{-4} x^2 - 0.377x + 307$. The temperature range of the initial blank for this die forging is 900—1 200 ℃, i.e., $x \in [900, 1\ 200]$ when $x = 1\ 200$, $Y_{min} = 53.32$. Therefore, when the initial billet temperature is 1 200 ℃, the average wear depth of the mold has a minimum value of 53.32 mm, which means the optimum initial billet temperature is 1 200 ℃.

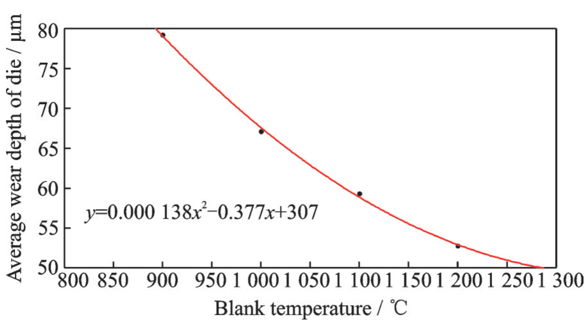

Fig.3 Die wear depth curve at different billet temperatures

As shown in Fig.4, the curve equation of mold temperature and mold wear amount is $Y = 4.62 \times 10^{-4} x^2 - 0.305x + 114$. The temperature range of the initial die forging is 250—400 ℃, i.e., $x \in [250, 400]$ when $x = 330.09$, $Y_{min} = 63.66$. Therefore,

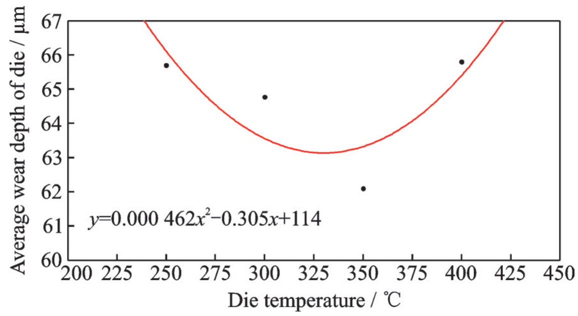

Fig.4 Die wear depth curve at different mold temperatures

when the initial mold temperature is 330.09 ℃, the average wear depth of the mold has a minimum value of 63.66 mm, that is, the optimum initial mold temperature is 330.09 ℃.

As shown in Fig.5, the curve of the forming speed and the mold wear amount is $Y = -7.8 \times 10^{-5} x^2 + 0.066x + 52$. The punching speed of the die forging is 300—600 mm/s, i.e., $x \in [300, 600]$ when $x = 600$, $Y_{min} = 63.52$. Therefore, when the forming speed x is 600 mm/s, the average wear depth Y of the mold has a minimum value of 63.52.

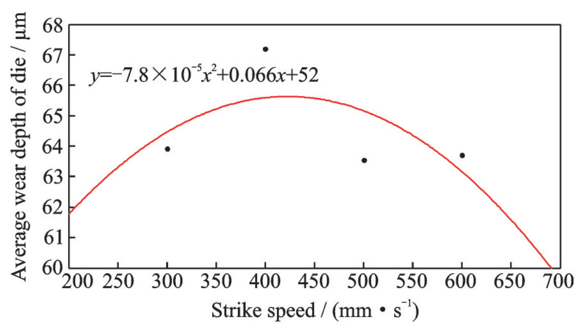

Fig.5 Die wear depth curve at different strike speeds

In summary, the optimal process parameters for minimizing the amount of mold wear during the forging process are: Initial billet temperature of 1 200 ℃, initial mold temperature of 330.09 ℃, and upper die strike speed of 600 mm/s.

3 Application of Finite Element Simulation

According to the optimal process parameters used in the die forging process derived above, further research is carried out, and deform finite element simulation software is used to simulate the whole process of forging machining under the conditions of the above optimal process parameters. The wear amount of the die forging die is calculated, and the life of die in the die forging under the optimal process parameters is predicted. The basic forgings commonly used in aviation engines are selected in this experiment: Transmission fasteners. They have certain typicality and their process flow has a certain representativeness in the aviation die forging process.

3.1 Establishing finite element simulation model

The upper mold, the lower mold, and the blank model required in this die forging process are constructed by the SolidWorks modeling software, and then imported into the Deform software in Stereolithography (STL) format to obtain the required finite element simulation model[19-22]. The die forging process parameters are set in the Deform. The unit system is selected as International System of Units (SI), the blank as a plastomer, and the mold as a rigid body. The material of the blank is TI-8AL-1MO-1V. The materials of the upper and the lower molds are all AISI-H-13. According to the optimal process parameters derived from the variance analysis, the current parameters are set. The billet temperature is set to be 1 200 ℃, the mold temperature 330.09 ℃, the upper die strike speed 600 mm/s, the thermal friction coefficient 0.7, and the heat transfer coefficient 11.

3.2 Finite element simulation results

Deform software is used to perform finite element simulation according to the set process parameters and the constructed model. The overall wear amount of the upper and the lower molds is obtained, and the wear of the upper and the lower molds is analyzed by selecting a mold with more severe wear, and extracting a plurality of points with large wear depth as critical nodes on the wear surface of the mold. The surface temperature, surface pressure, and wear depth of these key nodes are statistically calculated. The average wear amount during the die forging process is derived according to the mold wear correction model of the die forging process.

Fig.6 shows the forgings after the die forging, and Fig.7 shows the wear of the upper and the lower molds. Compared with the simulation results of the die forging process, the overall wear of the upper die is much more serious than that of the lower one. Therefore, seven key nodes with more serious wear conditions are extracted from the upper die surface.

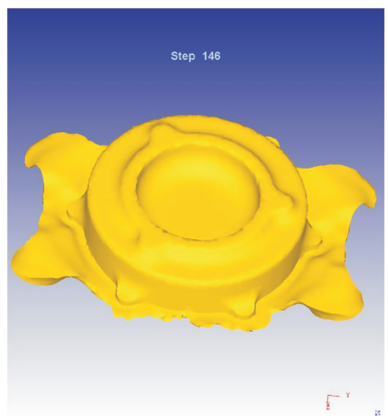

Fig.6 Forgings after die forging simulation

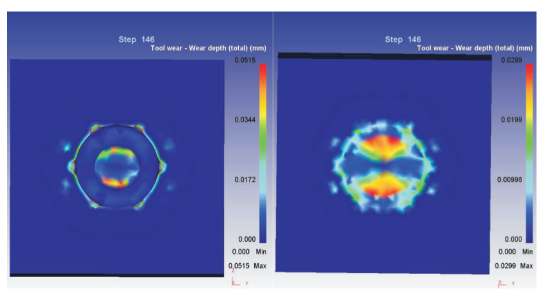

Fig.7 Die wear depth of upper mold (left) and lower mold (right)

Data analysis and data processing of surface temperature, surface pressure and wear of seven key nodes are performed using the Deform simulation software. Figs.8—10 show the surface temperature, surface pressure and wear of the seven key

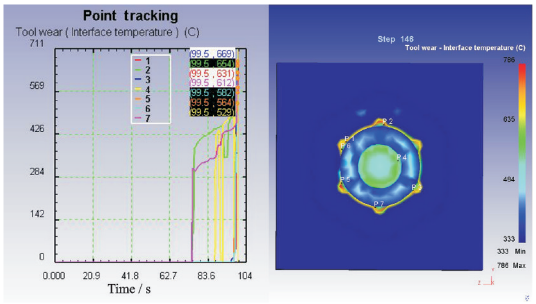

Fig.8 Surface temperature changes of seven key nodes on mold

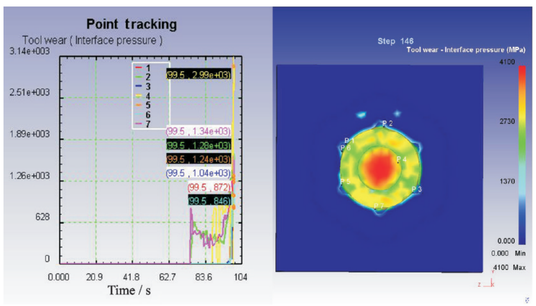

Fig.9 Surface pressure changes of seven key nodes on mold

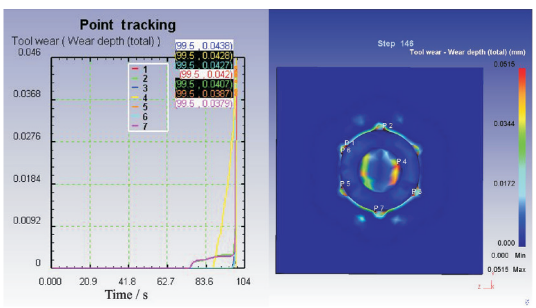

Fig.10 Variations in wear depth of seven key nodes on mold

nodes on the mold.

The average wear amount of the die forging process is calculated based on the wear amount of the seven key nodes and the mold wear correction model. The state of the mold after the end of the die forging is taken as the initial state of the mold at the beginning of the next die forging. Under the same conditions, the next die forging process simulation[23] is carried out. A total of 20 sets of finite element simulation tests for die forging process are carried out according to the above method, and the average wear amount of the mold after each simulation test is calculated.

4 Die Life Prediction Based on Polynomial Fitting

By analyzing and processing the test data of the above finite element simulation tests, the average wear amount is calculated according to the key nodes of the mold, and then the cumulative wear amount of the mold in the 20-time die forging simulation tests is obtained. According to the polynomial fitting method, the cubic curve fitting is performed on the results of the 20 test results, and the relationship between the cumulative amount of wear of a die in die forging and the number of die forging is derived. The curve is used to predict the service life of the mold. At the same time, the forging is subjected to on-site die forging test under the same conditions, and the life prediction method of the mold is verified on site.

4.1 Test data analysis and processing

Data statistics and data processing are performed on the simulation data of the seven key nodes, and the average wear amount in the die forging process is derived according to the mold wear correction model of the die forging process. Table 5 shows the parameter values of surface temperature, surface pressure, and wear depth for each critical node.

Table 5 Parameter values of each key node

Node number	Surface temperature / ℃	Surface pressure / MPa	Wear depth / μm
P_1	631	872	42.0
P_2	654	1 280	40.7
P_3	669	1 040	43.8
P_4	529	2 990	42.8
P_5	564	1 240	38.7
P_6	582	846	42.7
P_7	612	1 340	37.9

According to the wear amount of the key nodes and the mold wear correction model, the average wear amount of the die forging process is calculated. After calculation, $\overline{w} = 41.2$ μm. The above method is repeated to continue to calculate the average wear of the mold during the next 19 die forging processes. The average wear amount of the mold calculated by the nodal method is the cumulative wear amount of the mold in each die forging process. Table 6 shows the cumulative wear amount of the mold in the 20-time die forging simulation test.

Table 6 Cumulative wear of the die in 20 die forging tests

μm

Parameter	Tests 1—5	Tests 6—10	Tests 11—15	Tests 16—20
Cumulative wear of mold	41.2	139.4	185.8	215.3
	63.7	151.2	192.4	220.5
	74.9	155.4	196.6	227.2
	115.4	163.5	207.4	230.5
	134.7	170.4	211.6	233.4

4.2 Prediction of die life using polynomial fitting

The polynomial fitting method is used to fit the cumulative wear amount obtained by each die forging simulation test, and the mathematical relationship between the total wear amount of the die[24]. The times of die forging in the die forging process is derived. Data fitting to Table 6 is performed using a cubic curve, with the equation of $y=0.032\,5x^3-1.5x^2+28.1x+15$. Fig. 11 shows the fitting result between the total wear amount of the mold and the times of die forging. In actual production, the maximum precision error allowed by the mold is 0.5 mm, combining the polynomial fitting formula with the maximum precision error allowed by the mold. When $Y=500$, there is $X=33.64$, hence the service life of the mold is predicted to be 33 pieces by this method.

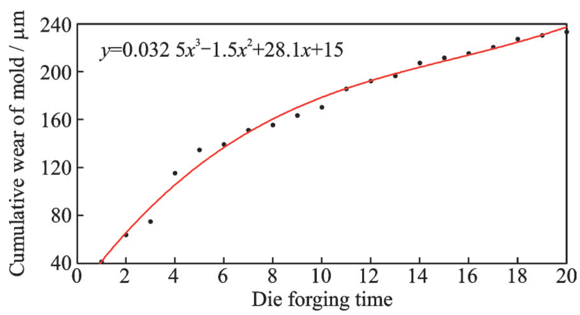

Fig.11 Fit curve between total wear depth of mold and times of die forging

4.3 Field experiment verification

Fig.12 shows the forging press, industrial computer and robot arm used in the field test. In the field experiment, the optimal solution of the forging process parameters derived from the paper is used to set the relevant process parameters, that is, the parameter setting of the die forging process is performed by the industrial computer. The initial temperature of the blank is set to 1 200 ℃, the initial temperature of the mold to 330.09 ℃, and the strike speed of the upper mold to 600 mm/s for the field die forging experiment. Since the test site lacks a precision instrument that can directly measure the cumulative wear of the mold, it is necessary to judge the failure of the mold by repeating the size of the forging obtained in the on-site die forging test, thereby predicting the service life of the mold.

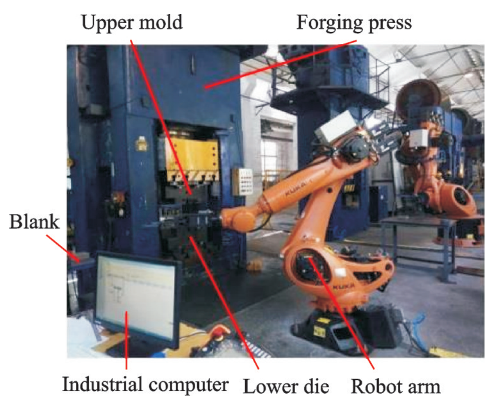

Fig.12 Apparatus of field die forging experiment

The results of the field test and the filling effect are the same as those of the finite element simulation. After the 33rd repeated forging, it is found that there are some defects on the surface of the forging. After measurement, it is found that the size of the forging is different from the standard size. Fig.13 shows the forging shape in the field experiment. From the 33rd test, the surface of the forging begins to have defects, and the forging size does not meet the production requirements. Therefore, the service life of the mold is 32 pieces. Using the mold life prediction method described in this paper, the theoretical die life is 33 and the actual die life is 32. The result error is only one piece. Hence, the mold life prediction method based on finite element simulation and polynomial fitting proposed in this paper has a practical guiding role for mold life prediction in hot forging forming process.

Fig.13 Forgings in the 33rd and 34th field tests

5 Conclusions

(1) Based on the Archard wear model, a mold wear correction model suitable for hot forging process is proposed, and three process parameters that have a great influence on the wear of mold in die forging die are derived, i.e., the initial temperature of the blank, the mold initial temperature, and the strike speed of the upper die. It is found that in the die forging process, the initial billet temperature has the greatest influence on the mold wear, and the initial temperature of the mold and the striking speed of the upper mold has less influence on the mold wear.

(2) The optimal solution of the die forging process parameters based on die wear is obtained by orthogonal test design and variance analysis: The initial billet temperature is 1 200 ℃; the initial mold temperature is 325 ℃; and the upper die striking speed is 600 mm/s. At this time, the amount of mold wear during the die forging process drops to its minimum of only 0.051 5 mm.

(3) A new method for calculating the amount of mold wear in the die forging process is proposed by correlating the die forging die wear correction model with the finite element simulation during the die forging process. The average amount of wear of the mold during the forging process is calculated by the amount of wear at critical points on the surface of the mold. At the same time, according to the calculation method of the average wear amount, a life prediction method of die forging die based on polynomial fitting method is proposed. Finally, the die life of the die forging process is 33 pieces. Through the on-site die forging test, the die life prediction method can accurately predict the die life in the die forging process.

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基于方差分析的模锻模具磨损研究及模具寿命预测

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摘要: 提出了一种模锻成型过程中基于模具磨损的工艺参数优化方法和一种基于多项式拟合的模具寿命预测方法。将正交试验中的方差分析法与模锻加工过程中的有限元仿真试验相结合,推导出模锻成型过程中对模具磨损影响程度最大的工艺参数及使模具磨损量实现最小值的工艺参数最优解。以热模锻工艺为例,在Archard磨损模型的基础上,推导出适用于热锻工艺的模具磨损修正模型,并且对热模锻中模具磨损过程进行基于Deform软件的有限元仿真分析。研究了热模锻加工过程中模具工作表面的磨损深度与模锻工艺参数之间的关系,利用正交试验设计和方差分析法推导出适用于热模锻的最优化工艺参数。通过计算模具表面多个关键性节点的磨损深度,根据模具平均磨损量和多项式拟合法来预测整个生产过程的模具使用寿命。

关键词: 模锻工艺;Deform;方差分析法;模具磨损;模具寿命预测