Modern Applied Science
www.ccsenet.org/journal.html
Vol. 3, No. 3
March 2009

Experimental Research of Optimal Die-forging Technological Schemes Based on Orthogonal Plan

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The research is financed by National Natural Science Foundation (Approval No. 60634020) and Hunan Province Natural Science Foundation (Approval No. 08JJ3132)

Abstract

Some problems on setting up die-forging technological scheme design criteria by means of traditional methods are analyzed. The idea of mining die-forging technological schemes based on orthogonal plan is pointed out. The height and width of the hub are selected as key factors from many ones which influence the die-forging technological schemes of axisymmetric forging, then, in connection with the two factors, the relative experiments are arranged by using the two-factor-twice-composition orthogonal plan. Flash metal consumption is choosed from a lot of factors as object function whose values are measured in the experiments. When the height and width of the hub are the constant, from several experimental schemes, the technological scheme which makes flash metal consumption be the least is selected as the optimal scheme, so the design criteria of optimal die-forging technological schemes are got. Because of adopting orthogonal plan in arranging the experiments, the design and manufacturing period of forging is reduced, the developing cost of forging is cut down, and the raw and processed material consumption is decreased. In laying down the design criteria of optimal die-forging technological schemes, optimal technology is combined with artificial intelligence. In determining the relations among so many factors in die-forging technological schemes, expert's experiences are used, and experimental results are dealt with by means of association rule mining technology, which makes the decision of die-forging schemes more reasonable and practical.

Keywords: Orthogonal plan, Factor, Optimal die-forging technological scheme, Design criterion, Association rule mining

The die-forging of axisymmetric forging is a complicated deformation process. Therefore, it is difficult to analyze and estimate it. So up to now, there have not yet been common design criteria of die-forging technological schemes. With the development of CAD technology, quantitative die-forging design criteria become increasingly urgent. Many scholars use such ways as theoretical analysis, experimental research or their combination (Xiao Jingrong, Li dequn Translation, 1983) to achieve this goal. As for theoretical methods, because of the complexity of die-forging production, either the analytic method, the main stress one, deformation work one, slip-line one, or discrete finite-cell one can only solve very simple forging problems and has a certain distance from guiding practical design. That is because, first, these methods make a lot of assumptions which have been quite different from actual production conditions; Second, it is difficult to determine border conditions which are not enough precise. In experimental methods, no matter which of the coordinate grid method,the inspect plasticity one and light plasticity one is used , it could be hard to achieve common design criteria. This has forced people to explore more effective ways to draw die-forging design criteria. In order to improve processes, enhance forging production capability, and enhance the utility of CAD systems, we analyzed some factory's forging die-forging technology of axisymmetric forging. On the basis of first-hand materials, we have decided to mine the design criteria of die-forging technological schemes of axisymmetric forging and to plan these experiments using the orthogonal design method. Thus, more effective data can be received with less experimental number and the corresponding design criteria of technological schemes of die-forging will have greater reliability. The aims of these experiments are to review flash metal consumption produced at every experiment and the quality of shaped forging, and thus determine the design criteria of optimal die-forging technological schemes of axisymmetric forging.

The strategy of orthogonal plan method is to make coefficient matrix become diagonal one after choosing appropriate factors, determining their variational ranges and making certain coding. Thus, the calculation of adverse matrix is simplified and the relativity of regression coefficients is eliminated. It is more important to obtain the desired sample number and factor values.

1. Orthogonal Plan of Experiments

1.1 Basis of Orthogonal Plan

The on-vehicle die-forging process of axisymmetric forging has the following characteristics: axisymmetric forging has a series of feature variables to best reflect its own characteristics(etc. shape complex coefficients, the height-to-width ratio of hub, and so on) most of which are always stable within a certain scope (for example, shape complex coefficients and the height-to-width ratio of hub are always between 1~5), and corresponding to these feature variables, a optimal technological scheme may be found, that is, on-vehicle die-forging has a optimal range. The range divisions to these feature variables with orthogonal plan may fully cover the information of these feature variables using less test points.

1.2 Strategy of Orthogonal Plan

The paper arranges experiments using twice composition orthogonal design. These experiments arranged in composition design have a series of advantages. Firstly, its test points are greatly less than the ones of three-level full-factor experiments, but maintain sufficient residual free degree; Secondly, they are received on the basis of one-time regression and if one-time regression is indistinct, asterisk points and central ones may be supplemented.

In the paper, two basic factors which are the height B and the width of hub are selected according to two-factor-twice-composition. In the case of two factors B and H, the number N of these experiments arranged in composition orthogonal design is 9. After standardized processing, a test point distributed list is received as shown in Table.1.

1.3 Choices of the Factors Affecting Die-forging Technological Schemes

1) Basis of the Choices of Factors

One of the aims to rationally determine die-forging technological schemes is to obtain high-quality forging. And to receive high-quality forging, metal must be filled with mould cavity. The factors affecting meta l moulding are multifaceted. On the shapes and sizes of axisymmetric forging (here mainly referring to the gear type), shape complex coefficients and the height-to-width ratio are two main factors affecting full moulding of metal. The two factors have both independence and the interaction. The paper uses the variety of the height and width of hub to affect the one of the two factors and the height and width of hub greatly affect shape complex coefficients. So the choices of die-forging technological schemes of axisymmetric may be seen as depending mainly on the two factors, the height and width of hub.

Some of the existing criteria determining die-forging technological schemes are mostly confined to a particular factor (i.e. the height-to-width ratio) as a basis in order to select technological schemes. In this paper, the two factors are inspected at the same time in determining the impact of the die-forging technological schemes. These are two mutually independent factors and in determining die-forging technological schemes, the height-to-width of hub is preferentially considered: When the height-to-width of hub is relatively large, even though shape complex coefficients are relatively small, it is advisable that once or twice pre-forging should be introduced. This is the difference between the design criteria and other ones.

2) Choices and Valuing of Factors

(1) Choices of Factors

As described above, the paper uses two steps to select factors: first selecting middle factors as shape complex coefficients of cold forging and the height-to-width ratio of hub and then selecting basic factors as the height and width of hub.

(2) Valuing of Factors

The valuing of factors and the determination of ranges must reflect the characteristics of forging produced in some factory. Specifically, the shape complex coefficients and the height-to-width ratio are all selected between 1and 5.The fluctuating range of basic factors is determined by means of the following ways: first adding up the production data of some factory in order to receive the fluctuating range of factors in actual production process; then proportionately reducing statistical data in order to gain experimental data according to the principle "when experimental results are applied to reality, geometric similarity, physics one and external environment one must be met. " statistics will be to the experimental data. Experimental data should ensure that the shape complex coefficients and the height-to-width ratio of experimental forging are roughly equal to the ones of actual forging. According to the analysis of the site production data, statistical data of H and B are received as shown in table.2.

After proportionately reducing statistical data of B and H and properly adjusting them, experimental data of B and H are received as shown in table.3.

According to the experimental data of B and H and the discussion about experimental composition, Experimentalplan list is gained as shown in table.4.

2. Determination of Optimal Die-forging Technological Schemes

2.1 Experimental Design and Processing Ways of Experimental Results

1) Experimental Design

Owing to short time, this paper could not complete the tests for nine types of forging. Only five typical types of forging are selected for the tests. Such feature parameters as shape complex coefficients, the height-to-width ratio of hub, and so on are displayed in Table.5.

Seen from Table.5, The shape complex coefficients and the height-to-width ratio of hub of the five types of forging cover a large range. Despite the relatively little number of experiments, the results of the experiment are still lost general.

Three Experiments are made for each type of forging, and the die-forging technological schemes of three experiments are free-upsetting—finish-forging, free-upsetting—pre-forging—finish-forging, and free-upsetting—pre-moulding-pre-forging—finish-forging respectively.

2) Processing Ways of Experimental Results

The aim of the experiments is to determine the magnitude of flash metal consumption produced at each experiment and thus develops the design criteria of optimal die-forging technological schemes.

In actual production, in judging the good or the bad of some technological scheme, except the quality of forging, such factors as flash metal consumption, die life, the complexity of die structure, operating convenience, and so on are also taken into consideration. Namely, The technological schemes which can achieve the best techno-economic benefit are the optimal ones.

On the conditions of the experiments, such factors as flash metal consumption, die life, the complexity of die structure, operating convenience, and so on are hard to be inspected. Therefore, in judging the good or the bad of some technological scheme only the factors, the quality of forging and flash metal consumption are considered. For each technological scheme, the design of its process step has to ensure metal fully moulded. Therefore, in this paper, optimal technological schemes of forging are determined by means of using the magnitude of flash metal consumption as object function and at the same time inspecting forging cost.

The design principles of the optimal technological schemes decided in the sense of less flash metal consumption and lower forging cost are: when the scheme, free-upsetting—finish-forging, is compared with the one, free-upsetting—pre-forging—finish-forging, or the scheme, free-upsetting—pre-forging—finish-forging, with the one, free-upsetting—pre-moulding-pre-forging—finish-forging, the former is preferentially considered. At the time, it is not much meaningful to reduce material consumption and the former is helpful for reducing die-forging process steps, simplifying die structure, increasing productivity, thereby reducing forging costs; Otherwise, the schemes which make flash metal consumption less are considered in order to make object function the least.

2.2 Experimental Results and Analysis of Material Consumption

After summing up and coordinating test data of 15 experiments at 5 test points, the experimental results of material consumption are received as shown in Table.6.

Seen from Table.6,for tested Piece F1, The flash metal consumption of Experiment F12 is the least, its optimal technological scheme is free-upsetting—pre-moulding--pre-forging—finish-forging; for tested Piece F2, The flash metal consumption of Experiment F22 is the least, its optimal technological scheme is free-upsetting—pre-moulding--pre-forging—finish-forging; for tested Piece F3, F4, and F5, their flash metal consumption of respective three tests is almost the same, but introducing pre-forging is helpful for prolonging die life and decreasing waste rate, their optimal technological scheme is selected as free-upsetting—pre-forging—finish-forging .

Based on the above analysis, the optimal technological schemes of five test points are shown in Table.7.

3. Conclusions

According to Table. 7 and 5, The corresponding relations between the optimal technological schemes of axisymmetric forging, and the shape complex coefficients of forging and the height-to-width ratio of hub B/H can be found, thereby the design criteria of the optimal die-forging technological schemes of axisymmetric forging can be gained as shown in Figure.2.

From Figure.2, the following conclusions can be shown:

(1) The optimal die-forging technological schemes of axisymmetric forging can be determined by means of the shape complex coefficients and the height-to-width ratio of hub;

(2) With the increase in the shape complex coefficients and the height-to-width ratio of hub , introducing pre-forging is helpful for reducing the flash consumption, prolonging die life and decreasing waste rate.

Due to the following reasons, The design criteria have to be consummated and modified before being applied to actual production. These reasons include: there are the greater differences between the experimental environment (including materials, deformation temperature, deformation rate and semifinished materials processing methods) and the actual situations of productions; Because of limited time, the orthogonal design only determines the two sizes, the height and width of hub, and shape complex coefficients are adjusted by modifying the height-to-width ratio of hub. Therefore, there are the large interaction and poor independence between shape complex coefficients and the height-to-width ratio of hub. Clearly, the design criteria of optimal die-forging technological schemes received in the paper is not enough accurate. Further research shows that the independence between the two factors can be modified through adjusting external sizes of hub and thereby, the more acute and actual design criteria of optimal die-forging technological schemes may be set up; Little test points make the design criteria not enough perfect.

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Table 1. Test Point Distributed List

Experimental No.	Factor Valuing	Explanation
1	(1 1)	Full-factor tests of (+1 –1) are composed of four test points: $m = 2^2 = 4$
2	(1 -1)	
3	(-1 1)	
4	(-1 –1)	
5	(γ 0)	The four test points are distributed in asterisk positions of Axes B and H: $2p = 4$
6	(-γ 0)	
7	(0 γ)	
8	(0 –γ)	
9	(0 0)	The central test point is composed of The zero-level of B and H: $m_0 = 1$

Table 2. Statistical data of H and B

Factors	Fluctuating Range	
	Max	*Min*
H	24.00	10.00
B	29.50	10.65

Table 3. Test data of H and B

Factors	Fluctuating Range	
	Max	Min
H	17.00	13.00
B	24.00	18.00

Table 4. Experimentalplan list

Experimental No.	Factors	
	H	B
1	17.00	24.00
2	17.00	18.00
3	13.00	24.00
4	13.00	18.00
5	17.00	21.00
6	13.00	21.00
7	15.00	24.00
8	15.00	18.00
9	15.00	21.00

Table 5. Feature Parameters of Experimential Samples

Numbers of Test Pieces	Feature Parameters			
	H	B	S	H/B
F_1	17.00	24.00	3.56	4.25
F_2	17.00	18.00	3.21	3.09
F_3	13.00	18.00	2.89	2.49
F_4	17.00	21.00	2.65	2.14
F_5	15.00	18.00	2.43	1.86

Where $F_i(i=1,\dots,5)$ is the number of tested forging according to the large-to-small order of shape complex coefficients.

Table 6. Material Consumption List

Experimental No.	Material Consumption		
	Total Weight	Weight of Forging	Weight of Flash
F_{11}	484.0	443.4	40.6
F_{12}	461.4	440.0	21.4
F_{13}	522.2	478.4	43.8
F_{21}	507.7	468.7	39.0
F_{22}	505.0	481.4	23.6
F_{23}	514.6	489.0	37.6
F_{31}	515.0	496.9	38.3
F_{32}	509.1	473.0	36.1
F_{33}	527.9	485.4	42.5
F_{41}	526.4	490.2	36.2
F_{42}	517.1	481.5	35.6
F_{43}	523.6	499.0	28.6
F_{51}	531.8	500.9	30.9
F_{52}	465.1	463.8	21.3
F_{53}	521.8	495.3	26.5

Where $F_{ij} * i=1,\dots 5, j=1,\dots 3)$ is the experimental number, I is the number of tested pieces, and j is the experimental order of some tested piece. The corresponding technological schemes are:

(1) free-upsetting—finish-forging;

(2) free-upsetting—pre-moulding-pre-forging—finish-forging;

(3) free-upsetting—pre-forging—finish-forging.

Table 7. Optimal Technological Scheme List

Tested Piece No.	Optimal Die-forging Technological Schemes
F_1	free-upsetting—pre-moulding-pre-forging—finish-forging
F_2	free-upsetting—pre-moulding-pre-forging—finish-forging
F_3	free-upsetting—pre-forging—finish-forging
F_4	free-upsetting—pre-forging—finish-forging
F_5	free-upsetting—pre-forging—finish-forging

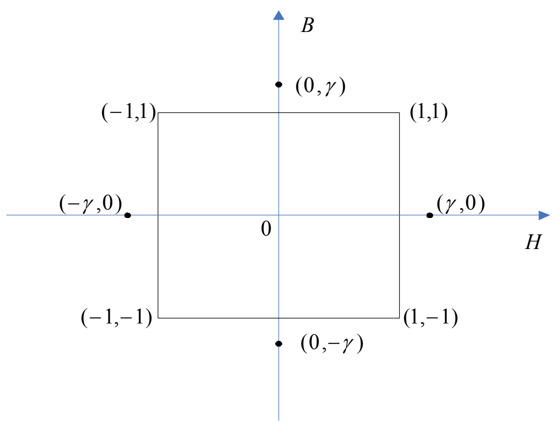

Figure 1. Experimentalconstruct for two-factor-twice-composition orthogonal plan

Where $\gamma = 1$, as shown in Figure 1.

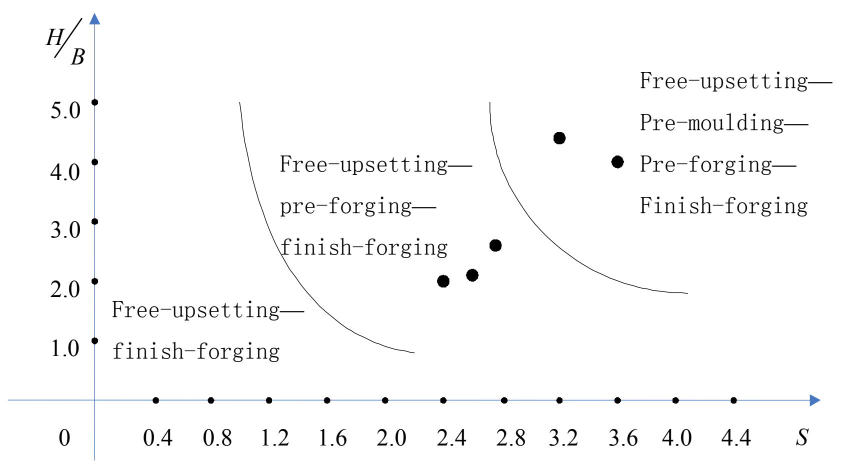

Figure 2. Design Criteria for the Optimal Die-forging Technological Schemes of Axisymmetric Forging