Applied Mechanics and Materials *Online: 2009-10-12*
ISSN: 1662-7482, Vols. 16-19, pp 515-519
doi:10.4028/www.scientific.net/AMM.16-19.515

Research on Influence of Process Parameters on Sheet Metal Extrusion Force

Hua Xiang[1,a], Xincun Zhuang[1,b] and Zhen Zhao[1,c]

[1]Dept. of Plasticity Forming Engineering, Shanghai Jiao Tong University, Shanghai, China, 200030

[a]hua2003@sjtu.edu.cn, [b]georgezxc@sjtu.edu.cn, [c]zzhao@sjtu.edu.cn

Keywords: Sheet metal extrusion force, Process parameters, Orthogonal experimental design

Abstract. Extrusion force plays a significant role on sheet metal extrusion process. It is characterized by various process parameters including material properties, extrusion ratio, friction, tool shape etc. In this paper, a reasonable FEM model of sheet metal extrusion process was established and validated by comparing the results of simulation and experiment firstly. Based on the reliable model, the effect on extrusion force of various process parameters was investigated with orthogonal experimental design combined FEM simulation. The work presented in this paper has laid certain foundation for further work of modeling and optimizing extrusion force.

Introduction

Nowadays, sheet metal extrusion as an important part of advanced metal forming technologies, has become a priority forming process which combines stamping or fine-blanking to produce components with the protruded part or the blind cavity as the positioning element in fields of automobile, information, electron and so on [1]. The extrusion force plays a significant role in the whole process planning including strip layout arrangement, tool design and press selection. It is characterized by various process parameters including material properties, friction, extrusion ratio, die shape and so on. Optimizing these process parameters with their influences on the extrusion forces is helpful to the smallest energy consumption, longer tool life and the quality of the finished product. Though numerous investigators have studied and modeled the force of conventional extrusion in the past several decades [2-3], sheet metal extrusion is different from the conventional extrusion. It is a further combined process in which the punch penetration and the extrusion take place at the same time [4]. Until now, few researches have been carried on sheet metal extrusion.

As various process parameters in sheet metal extrusion affect the extrusion force, it is costly and time-consuming to study each parameter's influence by experiments. To solve this problem, process modeling by computer simulation as virtual experiments can be used to replace physical experiments. In recent years, with the rapid development of computer technology, finite element method (FEM) has been one of main methods of studying complex deformation. Many FEM models have been established and verified for metal-forming processes including conventional extrusion [5-6], so it is possible to study sheet metal extrusion with FEM simulation in details.

In this paper, as the first step of this study, a reasonable FEM model of sheet metal extrusion process was established. Meanwhile, the validity of the model was verified by comparing the results of simulation and experiment under the same conditions in terms of forming load. Finally, based on the model, the effect on extrusion force of related process parameters was investigated with orthogonal experimental design (OED) combined FEM simulation.

FEM Simulation Model and Experiment Verification

Finite Element Software MSC. Marc was used in simulating sheet metal extrusion process. Since the process is symmetric in nature, the 2D symmetric model was chosen as shown in Fig.1. Considering deformation mainly occurred near the punch, the diameter of simulation region was limited as 30mm. The shape of the elements of the extruded material was rectangular and approximate 1200 elements were initially designed for the workpiece. Additionally, because the deformation is very uneven over the whole deformation field, to maintain computational accuracy and avoid the divergence of the calculations, remeshing procedure would be carried out in this case when strain changes reached 0.4.

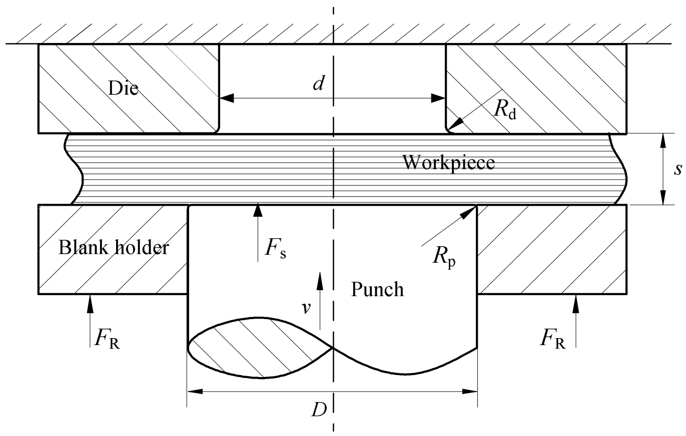

Fig.1 Geometrical model of sheet metal extrusion

The FEM simulation conditions are shown in Table1. Cold-rolled and 100% spheroidized carbide steel sheet C15E(EN) was used as the workpiece material, and a flow curve was determined by tensile testing experiments and its mechanical properties with Ludwik hardening material model. With the strength coefficient value 420 and the strain-hardening exponent value 0.54 which were calculated from the tensile testing, flow curve equation was obtained where K_f is flow stress and ε_P is plastic strain. Furthermore, friction coefficient 0.1 was used which was investigated in the previous study [4]. Because the velocity of punch is slow in sheet metal extrusion, the influences of strain rate and temperature on the deformation were be neglected in this study.

Table 1 FEM simulation conditions

Simulation Model	
Object type	Workpiece : Elasto-plastic Punch/die: Rigid Blank holder: Rigid
Work material	C15E, *s*= 4 [mm]
Flow curve equation	$K_f = 418 + 420 \cdot \varepsilon_p^{0.54}$
Tool geometry	Punch's diameter *D* : 12 [mm] Outlet's diameter *d* : 10 [mm] Punch edge's radius R_p : 0.3 [mm] Die edge's radius R_d : 0.3 [mm]
Blank holder force (F_R)	60 [kN]
Velocity of punch (v)	5 [mm/sec]
Friction coefficient (μ)	0.1

In order to prove the reliability of the FEM model established above, extrusion force in the process from the simulation was compared with that from experiment [6]. A tool was designed for experiments as shown in Fig. 2 and a 3200kN double action hydraulic press was used in which the blank holder force can be set independently. In order to obtain accurate experimental data, full-bridge strain gauge configurations were mounted onto the punch to measure extrusion force. With the same conditions in Table 1 for the FEM and experiment, Fig. 3 shows the comparison of extrusion force respect to punch stroke between the experiment and the simulation. The results about the extrusion force from simulation and experiment are similar and the approximate error is less than 10%. Therefore, there is a reasonably good agreement between the simulation and the experiment. It can be said that the model established in the paper is reasonable and reliable.

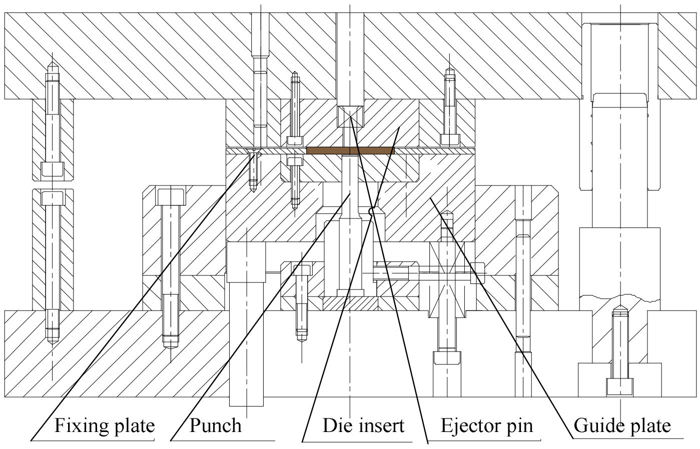

Fig.2 The structure of experiment tool

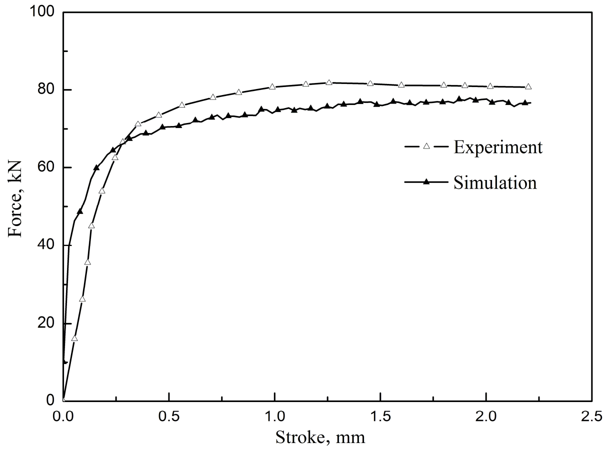

Fig.3 Results of simulation and experiment

Orthogonal Design and Simulation Plan

Considering various process parameters affect the force in sheet metal extrusion, it is important to find the key influence parameters that are the foundation of modeling and optimizing sheet metal extrusion force. Because OED is a powerful tool to qualitatively analyze the correlations among the relevant variables at different levels through designing orthogonal table and statistic analysis, in this study, the quantitative evaluation and statistic analysis of the effects of various process parameters were investigated on the extrusion force through orthogonal designing. Meanwhile, since the model mentioned above is reliable, physical experiments in orthogonal experimental design were replaced by FEM simulation which is more efficient and less costly. The flow chart of research work is shown as Fig.4.

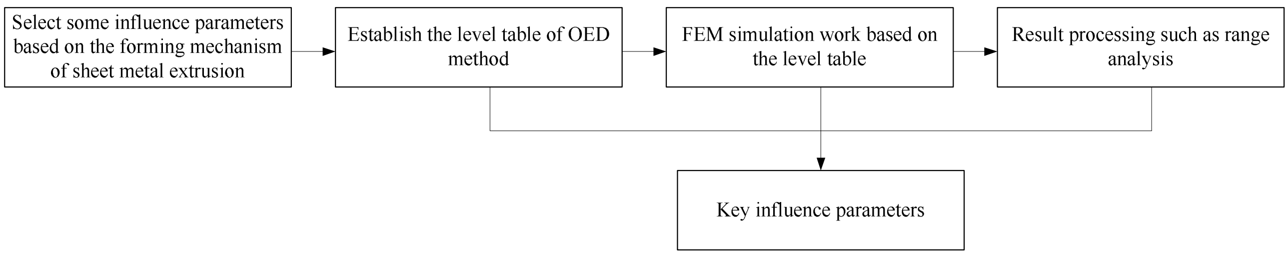

Fig.4 Flow chart of key influence parameters research

Base on the forming mechanism of sheet metal extrusion, six influential parameters of material type, area reduction ε_F, sheet metal thickness s, punch edge radius R_P, die edge radius R_d, friction μ

were chosen and named from A to F respectively, and three levels were set for each parameter according to the possibility (Table 2).

Table 2 Parameters and their levels

Level	Material type A	ε_F (%) B	s (mm) C	R_P (mm) D	R_d (mm) E	μ *F*
1	C15E	30	3.0	0.10	0.10	0.1
2	C45E	50	4.0	0.30	0.30	0.2
3	42CrMo4	70	5.0	0.50	0.50	0.3

Among orthogonal tables, the appropriate one for arranging the six parameters above with three levels for each is L_{18} (3^7). No interaction among the six parameters was assumed here. The plan of optimization was to investigate the effect of these six parameters on extrusion force (Table 3).

Results and Discussion

After the L_{18} (3^7) table was selected, simulations were carried out based on the established model. Results were measured and entered in the last column of Table 3. *F* is the extrusion force when the punch penetration depth reaches 1.0mm.

Table 3 Process parameters for numerical simulation and corresponding result

144

Exp. No.	Material type	ε_F (%)	s(mm)	R_P (mm)	R_d (mm)	μ	*F*
1	C15 E	30	3.0	0.1	0.1	0.1	61.8
2	C15 E	50	4.0	0.3	0.3	0.2	110.4
3	C15 E	70	5.0	0.5	0.5	0.3	163.6
4	C45 E	30	3.0	0.3	0.3	0.3	98.6
5	C45 E	50	4.0	0.5	0.5	0.1	147.6
6	C45 E	70	5.0	0.1	0.1	0.2	221.6
7	42CrMo4	30	4.0	0.1	0.5	0.2	126.4
8	42CrMo4	50	5.0	0.3	0.1	0.3	194.9
9	42CrMo4	70	3.0	0.5	0.3	0.1	242.7
10	C15 E	30	5.0	0.5	0.3	0.2	94.4
11	C15 E	50	3.0	0.1	0.5	0.3	103.4
12	C15 E	70	4.0	0.3	0.1	0.1	155.0
13	C45 E	30	4.0	0.5	0.1	0.3	114.0
14	C45 E	50	5.0	0.1	0.3	0.1	160.4
15	C45 E	70	3.0	0.3	0.5	0.2	214.0
16	42CrMo4	30	5.0	0.3	0.5	0.1	147.7
17	42CrMo4	50	3.0	0.5	0.1	0.2	166.4
18	42CrMo4	70	4.0	0.1	0.3	0.3	268.9

In orthogonal experimental design, the range analysis can be used to clarify the significance levels of different influencing parameters. And those most significant parameters could be disclosed basing on the result of range analysis. T_1, T_2, T_3, averages of extrusion forces for six parameters under three levels are in Table 4 and Fig.5. Fig.5 shows that there is no obvious influence of R_P and extrusion force increases a lot with material change and area reduction.

Table 4 Analysis of forming force

Factors	Material type(A)	ε_F (B)	s(C)	R_P(D)	R_d(E)	μ (F)
T_1	114.8	107.2	147.8	157.1	152.3	152.5
T_2	159.4	147.2	153.7	153.4	162.6	155.5
T_3	191.2	211	163.8	154.8	150.5	157.2
R	76.4	103.8	16.0	3.7	12.1	4.7
Sum of squares	2945.8	5481.6	130.9	7	85.25	11.33

The range value (R) for each parameter is the difference between the maximal and minimal value of the three levels. And the square of deviation (S) of three levels for each parameter was also obtained accordingly. Based on the results of range analysis and the square of deviation, the significance sequence of all the investigated influencing parameters was lined. For the extrusion force, the order of significance levels was as follows: area reduction, material type, sheet metal thickness, die edge radius, friction, punch edge radius. Furthermore, it could be concluded that material type and area reduction had further more influence on sheet metal extrusion force than other parameters. Therefore the key influence parameters are material type and area reduction. In order to optimize extrusion force, it is important to select the proper material and area reduction.

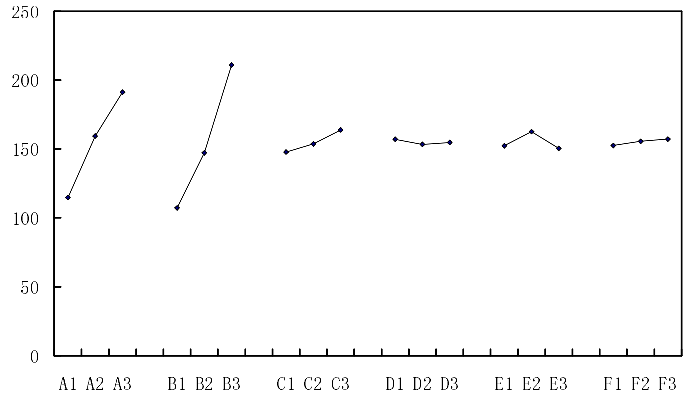

Fig.5 Main effects of plot-data mean for forming redundancy

Conclusions

Orthogonal analysis combined FEM simulation is introduced in the current study to investigate effect of the process parameters on sheet metal extrusion force, which is not only reliable and efficient, but also referential to other systems. The result shows that the effect levels of six investigated parameters are in the following order from the largest to the smallest: area reduction, material type, sheet metal thickness, die edge radius, friction, punch edge radius. Especially, area reduction and material type as key parameters have further more influence on the extrusion force than others.

Acknowledgements

Supported by Research Fund for the Doctoral Program of Higher Education of China, 20070248056

References

[1] P.F. Zheng, L.C. Chan and T.C. Lee: Int. J. Numer. Meth. Eng., Vol. 66 (2006) No. 3, pp.404-430.

[2] S. Storen: Int. J. Mech. Sci., Vol. 35 (1993) No.12, pp.1007-1020.

[3] Y.S. Kang and D.Y. Yang: Int. J. Mach. Tools Manufac., Vol. 36 (1996) No.8, pp.907-924.

[4] X.C. Zhuang, Z. Zhao and H. Xiang: Trans. Nonferrous Met. Soc. China, Vol. 18 (2008) No.5, pp.1172-1176.

[5] Q. Li, C.J. Smith and C. Harris: J. Mater. Process. Tech., Vol. 135 (2003) No.2, pp.189-196.

[6] Y.S. Lee, S.K. Hwang and Y.S. Chang: J. Mater. Process. Tech., Vol. 113 (2001) No.1, pp.136-140.