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Sectional Shape Analysis of Aluminum Alloy Seat Tube of Bicycle

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There are currently many different forms and manufacturing methods for bicycle seat tubes on the market. The primary purpose of this study is to design a bicycle seat tube extrusion die to meet a company's needs. We first designed a die with the sectional shape of a bicycle's seat tube using the DEFORM^{TM} 3D commercial finite element software. A series of simulation analyses in which the variables depend on different thicknesses of the long axis and short axis of the seat tube are reveal the effectiveness of decreasing the warp and force deformation in the bicycle seat tube extrusion process. These simulations assume that the die is a rigid body. We used the Taguchi method to find the optimum parameters of eight design factors. The simulation results of this study provide insight into the optimal processing conditions of the sectional shape of an aluminum alloy bicycle seat tube.

Keywords: *Bicycle seat tube, Finite element, Taguchi method.*

1. Introduction

There are currently many different forms and manufacturing methods for bicycle seat tubes on the market. For the extrusion processing method, Ulysse and Johnson [1] proposed a model that guides the preliminary design of extrusion dies, focusing on the deformation of the extruded product caused by exit velocity variations. Jo *et al.* [2] analyzed porthole die extrusion processes using 3D FE simulation in the non-steady state. They analyzed the variables of initial billet temperature, bearing length, tube thickness, and extrusion ratio throughout the entire manufacturing process. Chanda *et al.* [3] used 3D FEM simulations based on a rigid-viscoplastic formulation to examine the respective effects of the extrusion ratio and ram speed on the temperature evolution within extruded AA6061 aluminum alloy billets. Schikorra *et al.* [4] analyzed the microstructural evolution of extruded AA6060, AA6082, and AA7075 aluminum billets, using simulation results to construct micro- and macro-scale material models for predicting the grain size development.

Zhou *et al.* [5] used numerical simulations to investigate the isothermal extrusion of 7075 aluminum billets using a varying ram speed. Based upon the simulation results obtained from a series of constant ram speed extrusion runs, they presented two ram speed profiles for the isothermal extrusion of aluminum billets at temperatures of 480^{o}C and 500^{o}C, respectively. The current author [6] employed rigid-plastic finite element DEFORM^{TM} 3D software to investigate the plastic deformation behavior of Ti-6Al-4V titanium alloy during its indirect extrusion through a single-hole die in the seamless tube fabrication process.

The current study uses DEFORM^{TM} 3D software to investigate the plastic deformation of A6061 aluminum alloy during its extrusion through an elliptic mandrel die. This study also uses the Taguchi method to determine the optimum design parameters. Results confirm the suitability of the proposed design process, which allows an extrusion process mold and die to achieve a perfect design using the finite element method.

2. Simulation Process Analysis

This study adopts the following assumptions: (1) the mandrel and extrusion die are rigid bodies; (2) the aluminum alloy (A6061) is a rigid-plastic material; and (3) the friction factors between the workpiece and the mandrel and extrusion die remain constant during the extrusion process. Since researchers typically adopt the coulomb friction equation for cold working, and the shear friction equation for hot working, this study uses the shear friction equation for finite element analysis.

The Taguchi method uses a generic signal-to-noise (S/N) ratio to quantify variations. Depending on the characteristics involved, it is possible to use different S/N ratio criteria: “lower is better” (LB), “nominal is best” (NB), or “higher is better” (HB). William & Creveling [7] and Belavendram [8] described the S/N ratio for the LB characteristics of the current ring rolling process as

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (1)$$

where n represents the number of simulation repetitions under the same design parameters, y_i represents the measured results, and i represents the number of design parameters in the Taguchi orthogonal array (OA).

Figure 1 presents a schematic illustration of the aluminum alloy (A6061) extrusion process. We modeled the friction at the elliptic mandrel/die workpiece interface using the friction shear model. Figure 2 shows a schematic illustration of the sectional shape design of the elliptic mandrel and extrusion die. The outer diameter of seat tube used “d” symbol. The long axis dimension used “a” symbol and short axis dimension used “b” symbol for elliptic mandrel.

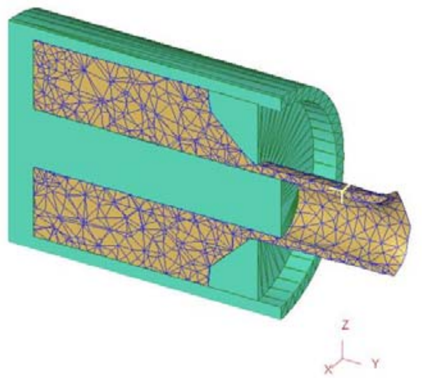

Fig. 1 Schematic illustration of the aluminum alloy (A6061) extrusion process

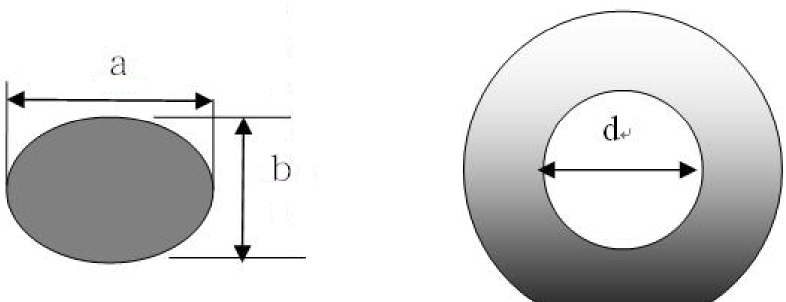

Fig. 2 Sectional shape design of the elliptic mandrel and extrusion die

3. Robust Design of Extrusion Process of Bicycle Seat Tube and Discussions

3.1 Factor Selection

The Taguchi experimental trials in this study adopted a locally designed mold and die for the extrusion process. Table 1 shows that the extrusion processes involved eight design factors, each with two or three levels. The experimental trials were arranged in an $L_{18}(2^1x3^7)$ orthogonal array matrix based on these variations. The extrusion process (Table 1) included the following design factors: factor A, strain rate; factor B: outer seat tube diameter; factor C: thickness of the long axis of the seat tube; factor D: thickness of the short axis of the seat tube; factor E: extrusion ingot diameter; factor F: outer mandrel depth; factor G: extrusion speed; and factor H: friction factor.

3.2 Analysis of Means

Table 2 shows the numerical data of the first simulation, while Table 3 shows the numerical data of the second simulation. Table 4 shows multi-quality characteristics: the "effective strain" weight is 20%, the "effective stress" weight is 20%, the "mold load" weight is 20%, and the "curvature of extruded product" is 40%. All the factors supported the rationale of "lower is better" (LB).

Table 1 Design parameters and levels for the extrusion process

Factors	Description	Level 1	Level 2	Level 3
A	Strain rate (s^{-1})	0.1	10	
B	Outer diameter of seat tube (mm)	27.2	30.8	31.6
C	Long axis thick of seat tube (mm)	2.0	1.5	1.0
D	Short axis thick of seat tube (mm)	2.8	3.1	3.4
E	Extrusion ingot diameter (mm)	80	90	100
F	Depth of outer mandrel	1	3	5
G	Extrusion speed (mm/sec)	0.2	0.4	0.5
H	Friction factor	0.1	0.3	0.5

Table 2 Numerical data of the first simulation

Sample 1	Effective strain	Effective stress (MPa)	Load of die/mold (N)	Curvature (κ)
case1	2.75	78	1261318.8	0.001784
case 2	2.65	78	1954149	0.000525
case 3	2.13	78	2125127.2	0.002237
case 4	2.93	78	2071658.6	0.000621
case 5	2.71	78	1946371.2	0.00086
case 6	3.17	78	1441241.8	0.000767
case 7	2.69	78	1715172.8	0.002177
case 8	3.3	78	1499744.2	0.003677
case 9	2.87	78	2302066.8	0.002694
case 10	3.08	123	3425857.2	0.000393
case 11	1.76	44.5	1227188	0.004928
case 12	3.45	123	3594062.6	0.006406
case 13	3.2	123	3800983	0.004529
case 14	2.51	123	2568954	0.001835
case 15	2.69	123	2558196	0.000452
case 16	3.26	123	2792753	0.001491
case 17	2.98	123	4283240.4	0.008404
case 18	2.84	123	1810038.8	0.000947

Table 5 presents the S/N response table for the bicycle seat tube extrusion process, while Table 6 presents the corresponding factor response data, which Fig. 3 plots in graphical form. According to the principles of the Taguchi method, a higher S/N ratio indicates higher product quality. Therefore, Fig. 3 shows the following optimal parameter settings for the seat tube extrusion process: *A1*, 0.1 strain rate; *B2*, 30.8 mm outer seat tube diameter; *C1*, 2.0 mm thickness of the long axis of the seat tube; *D3*, 3.4 mm thickness of the short axis of the seat tube; *E1*, 80 mm extrusion ingot diameter; *F2*, 3 mm outer mandrel depth; *G1*, 0.2 mm/sec extrusion speed; and *H1*, 0.1 friction factor.

3.3 Analysis of Variance

This study includes an analysis of the experimental trials based on ANOVA statistical analysis. Table 7 presents the corresponding results for the bicycle seat tube extrusion process. The high confidence (at least 90%) and variance of factors *A*, *F,* and *H* indicate that the strain rate, the depth of outer mandrel, and friction factor, respectively, have a significant influence upon multi-quality characteristics for the bicycle seat tube extrusion process.

3.4 Confirmation of Experiment

Figure 4 illustrates the curvature distribution of extruded products using perfect design (A1B2C1D3E1F2G1H1). These results indicate the ideal specifications of the new design's mold and die, with a perfect S/N ratio of 38.491 db.

Table 3 Numerical data of the second simulation

Sample 2	Effective strain	Effective stress (MPa)	Load of die/mold (N)	Curvature (κ)
case1	2.78	78	1261091.8	0.003176
case 2	3.58	78	2079341.8	0.000495
case 3	2.93	78	2562389.2	0.001109
case 4	3.31	78	2054673.2	0.002216
case 5	2.74	78	2088498	0.001575
case 6	2.95	78	1433251	0.001952
case 7	3.14	78	1618760.6	0.002105
case 8	2.58	78	1502861.2	0.001289
case 9	3.74	78	2307744.6	0.001106
case 10	2.88	123	3284569	0.000419
case 11	3.39	123	2263987	0.008075
case 12	3.34	123	3661269.4	0.00206
case 13	3.2	123	3800983	0.003037
case 14	3.11	123	2577419.4	0.003162
case 15	3.34	123	2481983.9	0.001048
case 16	2.79	123	2909665.8	0.000398
case 17	3.14	123	4426305.3	0.005423
case 18	2.78	123	1740251.6	0.001012

Table 4 Illustration of multi-quality characteristics

Criteria Description	Worst	Best Value	QC	Rel wt
Effective Strain	4	1.5	«S	20
Effective Stress	150	40	«S	20
Mold load	4500000	1200000	«S	20
Curvature	0.009	0	«S	40

4. Conclusions

This study uses finite element analysis to simulate the plastic deformation behavior of aluminum alloy (A6061) during the extrusion process. Results show the following optimal parameter settings: *A1*, 0.1 strain rate; *B2*, 30.8 mm outer seat tube diameter; *C1*, 2.0 mm thickness of the long axis of the seat tube; *D3*, 3.4 mm thickness of the short axis of the seat tube; *E1*, 80 mm extrusion ingot diameter; *F2*, 3 mm depth of the outer mandrel; *G1*, 0.2 mm/sec extrusion speed; and *H1*, 0.1 friction factor. The high confidence (at least 90%) and variance of factors *A*, *F,* and *H* indicate that the strain rate, the depth of the outer mandrel, and the friction factor, respectively, have a significant influence upon multi-quality characteristics.

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Table 5 S/N ratio of the bicycle seat tube extrusion process

	A	B	C	D	E	F	G	H	Sample 1	Sample 2	Average	S/N ratio
1	1	1	1	1	1	1	1	1	74.79	66.89	70.84	36.965
2	1	1	2	2	2	2	2	2	76.98	68.92	72.95	37.22
3	1	1	3	3	3	3	3	3	72.5	68.46	70.48	36.95
4	1	2	1	1	2	2	3	3	73.6	63.58	68.59	36.655
5	1	2	2	2	3	3	1	1	75.06	70.78	72.92	37.245
6	1	2	3	3	1	1	2	2	74.85	71.4	73.125	37.274
7	1	3	1	2	1	3	2	3	70.77	68.07	69.42	36.824
8	1	3	2	3	2	1	3	1	60.53	76.88	68.705	36.554
9	1	3	3	1	3	2	1	2	63.47	63.54	63.505	36.056
10	2	1	1	3	3	2	2	1	57.03	59.37	58.2	35.293
11	2	1	2	1	1	3	3	2	75.03	27.45	51.24	31.235
12	2	1	3	2	2	1	1	3	26.32	46.11	36.215	30.191
13	2	2	1	2	3	1	3	2	35.41	42.04	38.725	31.664
14	2	2	2	3	1	2	1	3	60.37	49.62	54.995	34.681
15	2	2	3	1	2	3	2	1	65.14	57.76	61.45	35.723
16	2	3	1	3	2	3	1	2	54.54	62.45	58.495	35.282
17	2	3	2	1	3	1	2	3	17.03	28.13	22.58	26.278
18	2	3	3	2	1	2	3	1	66.28	66.89	66.585	36.467
Total average											59.94556	34.92

Table 6 Factor response table of the bicycle seat tube extrusion process

Control factor	A	B	C	D	E	F	G	H
Leval 1	36.86	34.642	35.447	33.819	35.574	33.154	35.07	36.374
Level 2	32.979	35.54	33.869	34.935	35.271	36.062	34.769	34.788
Level 3		34.577	35.443	36.006	33.914	35.543	34.921	33.597
Effects	3.881	0.963	1.578	2.187	1.66	2.908	0.301	2.777

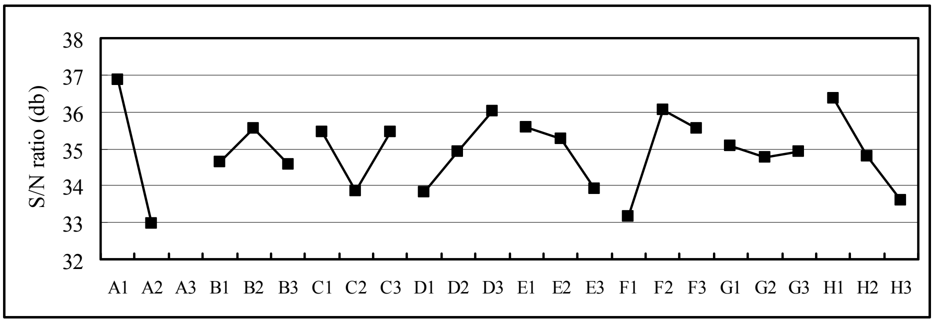

Fig. 3 S/N response graph of the bicycle seat tube extrusion process

Table 7 Analysis of variance (ANOVA) results for the bicycle seat tube extrusion process

Factor	*SS*	*DOF*	*Var*	F	Probability	Confidence	Significant?
A	67.783	1	67.783	57.51633	1.6946%	98.31%	Yes
B	3.475	2	1.7375	1.474332	40.4149%	59.59%	No
C	9.937	2	4.9685	4.215952	19.172%	80.83%	No
D	14.355	2	7.1775	6.090369	14.1036%	85.90%	No
E	9.378	2	4.689	3.978787	20.0852%	79.91%	No
F	28.865	2	14.4325	12.2465	7.5492%	92.45%	Yes
G	0.272	2	0.136	0.115401	89.6539%	10.35%	No
H	23.306	2	11.653	9.887993	9.1844%	90.82%	Yes
Error	2.357	2	1.1785	S=1.0856			
Total	159.733	17	9.396	*At least 90% confidence level			

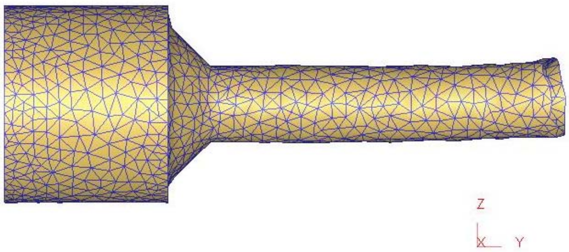

Fig. 4 Curvature distribution in extruded products using the perfect design (A1B2C1D3E1F2G1H1)

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