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Study on Hot Forming Parameters of Torsion Beam Based on Regression Analysis

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Abstract. It is found the hot forming quality has close related to the initial temperature of the pressing die, the blank, pressing speed, cooling rate and the friction between the part and tools. Through the design of orthogonal test and multiple regression analysis, the regression model of thinning rate and these factors are obtained. The model has 99% significance and credibility. By the variance analysis of independent variables and dependent variables, the confidence level is 99.91%, and the residual analysis results show a good correlation between the measured values and the calculated values. The results show that the modified model has high reliability.

1. Introduction

The torsion beam is an important functional component of cars' rear suspension system. The strength, stiffness and fatigue performance are the key points of the whole rear suspension system. For better energy saving and environmental protection, the automobile industry in the United States, Germany, Japan and South Korea have widely used the high pressure forming torsion beam for the purpose of lightweight part besides a better performance property. The conventional hydroforming process requires the material's tensile strength less than 700MPa, on top of that with increasing of the blank strength, forming precision is to be decreased. However, hot forming, as a new developed technique, overcomes these issues such as material's low plasticity, large deformation resistance, high resilience of cold forming and so on. Through mold quenching, the microstructure transforms into martensite from austenite while the tensile strength is up to 1500MPa.

In contrast to the traditional cold forming, the biggest characteristic of hot forming is that there is a constant temperature field in the forming process. As a result of this temperature field, the change of phase transformation and mechanical properties of the material may lead to the stress field of the material changed, thereofre the hot forming involves the coupling of temperature, stress and phase transition of the material.

2. An overview of regression analysis method

Regression analysis is a kind of multivariate statistical analysis, and it is an efficient mathematical tool to explore the law of science. Regression analysis is a method of two or more random variables of relevance. It not only provides the mathematical expression of the relationship between the variables, but is used for analysis of probability and statistics knowledge of this relationship. In order to determine its effectiveness, the formula is used by one or more variables which can forecast the control value of another variable to further predict, control and analyze the related factors. Regression analysis has been widely used as a analysis tool and is mainly to solve the following issues: ①to determine the correlation between several specific variables, if present, derived mathematical expressions; ②according to one or several variables, value prediction or control of another variable, and know that this forecast or control accuracy; ③the factor analysis between the primary and secondary factors and factors such as the relationship between. The variable x, a linear regression equation between Y, often through the regression equation to answer

such 2 questions: ①for any given observation point x_0, the approximate range of Y_0 estimation; ② if observations must y in a certain range of $Y_1<y<Y_2$ value control variable inference. The former is a forecasting problem, the latter is a control problem.

3. Experimental study

During the hot forming process, the part is heated to complete Austenitizing. Then the part is formed to the shape of the stamping die and further quenched inside the die. During the forming process, the stamping speed is to be controlled not to high, otherwise the parts could easily ruptured; at about 700℃austenite, the blank initial temperature greater than 700℃. However in the actual production process which is continuous, the initial temperature of the die has great influence on the phase transition in hot forming. For right microstructure and property to be obtained, the stamped part needs to be kept in pressure quenching mold for a certain period. Insufficient holding time will cause quenching incomplete, while over holding will affect the property as well as the production efficiency. The detailed Orthogonal test results with 16 group experiments obtained are shown in table 2

Table1 Level factor table

Factors	Pressing speed /mm	Initial temperature of the blank /℃	Initial temperature of the mould /℃	Quenching time/s	Friction coefficient
Level 1	50	750	50	1	0.4
Level 2	100	800	100	1.5	0.425
Level 3	150	850	150	2	0.45
Level 4	200	900	200	2.5	0.475

Table 2 Results

Factors	Pressing speed /mm	Initial temperature of the blank /℃	Initial temperature of the mould /℃	Quenching time/s	Friction coefficient	Thinning rate/%
	x1	x2	x3	x4	x5	y
1	50	750	50	1	0.4	4.185
2	50	800	100	1.5	0.425	3.78
3	50	850	150	2	0.45	2.143
4	50	900	200	2.5	0.475	5.155
5	100	750	100	2	0.475	5.172
6	100	800	50	2.5	0.45	6.335
7	100	850	200	1	0.425	8.771
8	100	900	150	1.5	0.4	14.449
9	150	750	150	2.5	0.425	16.853
10	150	800	200	2	0.4	17.762
11	150	850	50	1.5	0.475	100
12	150	900	100	1	0.45	100
13	200	750	200	1.5	0.45	100
14	200	800	150	1	0.475	22.109
15	200	850	100	2.5	0.4	23.639
16	200	900	50	2	0.425	100

4. Experimental results

4.1 Regression analysis

Establish regression equation:

$$Y=l+aX_1+bX_2+cX_3+dX_4+eX_5+fX_1^2+gX_2^2+hX_3^2+iX_4^2+jX_5^2+kX_1X_2X_3X_4X_5$$

X1, X2, X3, X4, X5 and Y represent respectively the stamping speed, the initial temperature of the blank, the initial temperature of the mould, quenching time, friction coefficient and thinning rate. l is constant and a~k is coefficient. So we can get a table 3.

Table 3 Regression statistics

Regression statistics	
Multiple R	0.996385
R Square	0.992782
Adjusted R Square	0.972934
Standard error	6.646546
Observed value	16

Table 4 Variance analysis

	df	SS	MS	F	Significance F
regression analysis	11	24306.33	2209.666	50.01896	0.000911
residual	4	176.7063	44.17657		
Total	15	24483.03			

Multiple R (complex correlation coefficient R) is the square root of R2, also known as the correlation coefficient, used to measure the degree of correlation between the independent variables X and y in Table 3. The relationship of complex phase is bigger and the relationship between variables is more and more closely. In this experiment, R=0.996385 showed that the relationship between them is highly positive. Square R is the complex coefficient of determination, the above complex correlation coefficient R of the square. To explain the degree of Y variation of the dependent variable to determine the fitting effect of the dependent variable y. The complex measurement coefficient in this experiment was 0.992782, which indicated that the 99.3% of the variation of the dependent variable can be explained by the independent variable. Adjusted R Square for the determination of complex coefficient R2 is adjusted, the value is 0.972934, the independent variable sheet stamping speed, initial temperature, initial temperature, mold pressing time, the friction coefficient can be explained by the variable thinning rate of 97.29%, due to the variable y 2.71% should be explained by other factors. Standard error is used to measure the size of the degree of fitting, but also for the calculation of other statistics related to the regression, this value is smaller, the better the degree of fitting.

Table 4 is the analysis of variance, the main function is to determine the regression effect of regression model by F test. Among them, Significance F (significant F statistic) corresponds to the F a critical value at a significant level, in fact, is equal to the P value, that is, the probability of the true probability. The so-called "abandoned true probability", that is, the model for the probability of false, obviously 1-P is the true probability of the model. Visible, the smaller the better P value. For this example, P=0.000911, the reliability of the confidence to reach more than 99.91%.

4.2 Regression parameters

Table 5 Regression parameters

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%	lower limit 95.0%	Upper limit 95.0%
Intercept	-4116.73	820.1285	-5.01961	0.007387	-6393.77	-1839.69	-6393.77	-1839.69
X1	-0.32986	0.196767	-1.67638	0.168971	-0.87617	0.216456	-0.87617	0.216456
X2	-2.30898	1.209154	-1.90958	0.128808	-5.66613	1.048169	-5.66613	1.048169
X3	-2.16639	0.211773	-10.2298	0.000515	-2.75436	-1.57841	-2.75436	-1.57841
X4	67.98865	24.28514	2.799599	0.048832	0.562291	135.415	0.562291	135.415
X5	22250.76	2585.935	8.604533	0.001003	15071.05	29430.47	15071.05	29430.47
X12	-0.00069	0.000667	-1.03512	0.359087	-0.00254	0.001162	-0.00254	0.001162
X22	0.001703	0.000723	2.354916	0.078095	-0.0003	0.00371	-0.0003	0.00371
X32	0.004256	0.000666	6.385244	0.003087	0.002405	0.006106	0.002405	0.006106
X42	-40.5631	6.649066	-6.10057	0.003653	-59.0239	-22.1023	-59.0239	-22.1023
X52	-24548.2	2926.261	-8.38894	0.001105	-32672.8	-16423.6	-32672.8	-16423.6
X1X2X3X4X5	1.45E-05	1.78E-06	8.185106	0.001213	9.6E-06	1.95E-05	9.6E-06	1.95E-05

The first column Coefficients corresponds to the regression coefficients of the model, which can be established by regression models in table 6:

$Y=-41165.73-0.32986X_1-2.30898X_2-2.16639X_3+67.98865X_4+22250.76X_5-0.00069X_1^2+0.001703X_2^2+0.004256X_3^2-40.5631X_4^2-24548.2X_5^2+1.45E-05X1_1X_2X_3X_4X_5$

The fourth column value P corresponds to the P value of the parameter (bilateral). When P<0.05, the model can be considered significant at the level of a =0.05, or the confidence degree is 95%; the X3, X4, X5, X22, X32, X42, X52, X1X2X3X4X5, P value is less than 0.05, so these items associated with Y, the P and independent variables, the rest is greater than 0.05, a description of these variables and dependent variables do not exist correlation, regression coefficient is not significant.

5. Conclusion

(1)The quality of the torsion beam is closely related to the initial temperature of the blank, the initial temperature of the die, the pressing speed, the cooling rate and the coefficient of friction. By means of orthogonal test and multiple regression analysis, the relevant factors are fitted, and the regression model is established:

$Y=-41165.73-0.32986X_1-2.30898X_2-2.16639X_3+67.98865X_4+22250.76X_5-0.00069X_1^2+0.001703X_2^2+0.004256X_3^2-40.5631X_4^2-24548.2X_5^2+1.45E-05X1_1X_2X_3X_4X_5$

The model has 99% credibility with 99.91% confidence level. The residual analysis results show a very good correlation between the measured value and the calculated value. The results show that the modified model has high reliability.

(2)Stamping speed, the initial temperature of the blank, the initial temperature of the mould, quenching time, friction coefficient and other variables can explain the variation of the 99.3% dependent variables, and to illustrate the dependent variable thinning rate of 97.29%, 2.71% of the dependent variable should be explained by other factors.

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