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The optimal clearance design of micro-punching die

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ABSTRACT

Purpose: The purpose of this research paper is focused on the optimal clearance design of micro-punching die by abductive network and SA method.

Design/methodology/approach: The punching data (input) and wear size (output) were collected for a training database. In order to select proper clearance to evaluate the wear of die, the abductive network was used to establish an efficient relationship between input parameters and output result. This can help to predict wear size under any degree of clearance and hence to replace worn punches and dies at the right time. A simulated annealing (SA) optimization algorithm with a performance index is then applied to the neural network for searching the optimal clearance parameters, and obtains rather satisfactory result as compared with the corresponding experiment verification.

Findings: This study aims to identify the relationship between clearance and service life of micro punches using the Neural Network, and to find relational data involving the service life of punches and punching parameters in non-metal blanking processes. The result can be used to estimate optimal clearance between punch and die for industrial applications.

Research limitations/implications: In this study, the practical punching processes with different punching conditions were carried out for a set of training data. A trained model exhibited a relationship between service life and clearance of micro punch and die through an abductive network system. The predicted value of wear by abductive network is very close to the actual experimental value, with an error of less than 8%. This result satisfies the required standard for IC factory production.

Originality/value: A good clearance design not only increases the quality of product manufactured, but also reduces product's burr. As a result, the wear of punches and dies can be greatly reduced and the life expectancy of punching dies increased.

Keywords: Optimal clearance design; Micro-punching die; Experimental design; Abductive network

1. Introduction

This study aims to identify the relationship between clearance and service life of micro punches using the Neural Network, and to find relational data involving the service life of punches and punching parameters in non-metal blanking processes. The result can be used to estimate optimal clearance between punch and die for industrial applications.

In the past, the clearance between punch and die was generally set up for drawing process. Conry, et al. [1-6] attempted to obtain the relationship between punch profile and die clearance via the optimization principle. Lieu, et al. [7] studied the best ways to obtain the parameters of optimal clearance and profile of punch and die during square drawing. Tai and Lin [8] also tried to obtain the optimal clearance value of punch and die during drawing process using the Neural Network and Simulated Annealing Method.

Luo [9] conducted experiments to obtain the optimal punching angle by using punches of different sizes during punching of round holes. Joo et al. [10] studied the micro-hole fabrication by mechanical punching process. Li et al. [11] studied the plastic status parameter and instantaneous clearance of a punching without burr. Cheung et al. [12], studied the relationship between IC packaged dam-bar and service life of punches. The clearance of punches and dies becomes smaller as a result of micro punching. This will adversely affect the accuracy of workpieces and reduce the service life of both punch and die components.

2. Experimental design

The experimental analysis used punches and dies made from high-speed steel subjected to surface grinding and heat treatment with hardness up to HRC 64. The punching machine was a punching speed of 15 m/min. In conjunction with IC chips packaging, punch and die must be rectangular and right-angled (R≦ 0.03mm). They have a short side AO and long side BO as shown in Fig. 1. The shearing angle of the punch's cutting edge was 12˚.

In order to explore the relationship between clearance and service life of the punch, eight groups of experimental data of side AO and side BO were established. The experimental data is listed in Table 1. Table 2 show experimental values in millions of units punched for punch and die. This was training data allowing for an abductive network to set up the relationship between input data (clearance and punching times) and output result (wear). Then PET+PE+HMT composites were used for experiment.

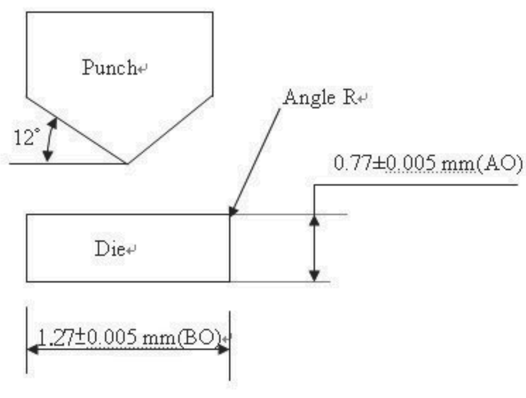

Fig. 1. Punch and die shape

Where PET is Polyetylene Terephthalate, PE is Polyetylene, and HMT is one of Thermoset Dyed Polymer. Fig.2 and Fig.3 shows the wear condition of the punch and die after 3 x 10^6 punching operation at a clearance of 0.015mm.

Table 1.
The experimental data of punch/die

Parameters	Level 1	Level 2	Level 3	Level 4
AO-side clearance, mm	0.015	0.018	0.021	0.024
BO-side clearance, mm	0.008	0.011	0.014	0.017

Table 2.
Compared of the neural network predict and experiment data

Condition	Punching times	Predicted value, mm	Experim. value, mm	Erro %
The AO-side wear of punch with clearance 0.015 mm	3×10^6	0.015	0.016	6
	8×10^6	0.045	0.046	4
The BO-side wear of punch with clearance 0.013 mm	3×10^6	0.027	0.028	7
	8×10^6	0.044	0.045	7
The AO-side wear of die with clearance 0.015 mm	3×10^6	0.796	0.821	3
	8×10^6	0.810	0.842	4
The BO-side wear of die with clearance 0.015 mm	3×10^6	1.290	1.402	8
	8×10^6	1.297	1.412	8

Fig. 2. The wear condition of the punch

Fig. 3. The wear condition of a die

3. Abductive network synthesis and evaluation

Abductive network is a specific neural network. In an abductive network, a complex system can be decomposed into smaller, simpler subsystems grouped into several layers using polynomial function nodes. The polynomial network proposed by Ivakhnenko [13] is a group of methods of data handling (GMDH) techniques. These nodes evaluate the limited number of inputs by a polynomial function and generate an output to serve as an input to subsequent nodes of the next layer. The general polynomial function in a polynomial functional node can be expressed as follows:

$$y_0 = B_0 + \sum_{i=1}^{n} B_i x_i + \sum_{i=1}^{n}\sum_{j=1}^{n} B_{ij} x_i x_j + \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n} B_{ijk} x_i x_j x_k + \cdots \quad (1)$$

Where x_i, x_j, x_k are the inputs, y_0 is the output, and B_0, B_i, B_{ij}, B_{ijk} are the coefficients of the polynomial functional nodes.

In this paper, several specific types of polynomial functional nodes are used in polynomial network to predict the residual blank length in some different kind of deep-drawing parameters. These polynomial functional nodes are named as normalizer (N), unitizer (U), white (W), singles (S), double (D) and triples (T) node.

To build a complete abductive network, the first requirement is to train the database. The information given by the input and output parameters must be sufficient. A predicted square error (PSE) criterion is then used to automatically determine an optimal structure [14]. The principle of the PSE criterion is to select the least complex yet still accurate network as possible. The PSE is composed of two terms; that is:

$$PSE=FSE+K_P \quad (2)$$

Where FSE is the average square error of the network for fitting the training data and K_P is the complex penalty of the network.

4. Relationship between punch/die clearance

An abductive network synthesizes a three-layer network automatically. It is comprised of design factors (punching times and clearance size) and output factor (wear value). The polynomial equations used in this network are listed in Fig. 4; input parameters include clearance of the punch/die and punching times. Output parameter includes the wear value of the punch's BO-side and AO-side. The others (die's AO-side and die's BO-side) individually have similar polynomial equations.

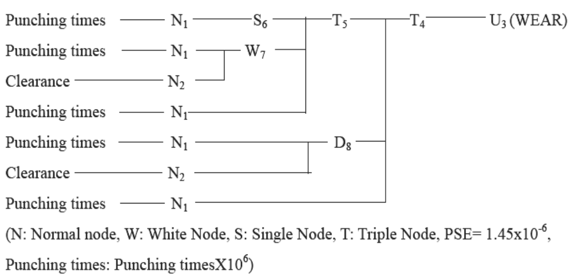

Fig. 4. The relationship between punching parameters and wear of punch's AO-Side

To verify the accuracy of the neural network, this study utilized another set of new dies for a wear test (see Table 2). The wear of punch AO side with clearance 0.015 mm at 3×10^6 th punching times is 0.016 mm by actual experiment, while the neural prediction is 0.015 mm, with an error value of 8%. The maximum error of the wear was on the die BO side with clearance 0.013 mm at 5×10^6 th punching times, the wear value of the neural network is 1.2972 mm, and actual experiment value is 1.4120 mm, with an error value of 8%.

5. SA method and optimal clearance values election

In this paper, the simulated annealing algorithm[15] is conducted to search for the optimal clearance parameter. The SA, initial temperature T_s, final temperature T_e, and a set of initial process parameter vectors O_x was given. The objective function obj is defined corresponding to the clearance values performance index. The objective function can be recalculated through all the different perturbed compensation parameters. If the new objective function becomes smaller, the perturbed process parameters are accepted as the new process parameters and the temperature drops a little in scale. That is:

$$T_{i+1} = T_i C_T \quad (3)$$

Where i is the index for the temperature decrement and the C_T is the decaying ratio for the temperature (C_T <1).

However, if the objective function becomes larger, the probability of acceptance of the perturbed process parameters is given as:

$$P_r(obj)=\exp\left[\frac{\Delta\ obj}{k_B T}\right] \quad (4)$$

Where k_B is the Boltzmann constant and Δobj is the difference in the objective function. The procedure is repeated until the temperature T approaches zero. It shows the energy dropping to the lowest state. And the optimal clearance values are obtained by using the objective function to serve as a starting point. The objective function obj is formulated as flows:

Obj= w*(Min. Wear)
(SA parameters: clearance and punching times) (5)

Where w is the weights function. In the meantime, the clearance values of the micro-punch should meet the simulation data method. In other words, the basic condition of optimization should fall in certain range, the die clearance and get from optimization should be larger than the minimum clearance, and is smaller then the maximum die clearance.

The upper bound conditions should be kept at an acceptable level during the search routine to reach the optimization clearance design.

6. Results and discussion

The simulation is used to illustrate the process of optimizing the clearance parameters. When the weight function w_1=1. The optimal parameters used in the simulation annealing algorithm are given as follows: the initial temperature Ts=100°C, the final temperature Te=0.0001°C, the decaying ratio CT=0.98, the Boltzmann constant k_s=0.00667. The upper bound of micro-punch system parameter is set to clearance= 0.024 mm , punching times= 8.27×10^6, and the lower bound of micro-punch system parameter is set to clearance =0.008 mm, punching times= 1.458×10^6. The simulated annealing is used for finding the optimal micro-punch system parameter as shown in Table 3.

The experimental data using punching process are shown in Fig. 5 through 6. The corresponding punching clearance in AO-Side is found to be 0.015mm and the punching times is set the max.-times= 8.67×10^6. By using this set of clearance parameters, the minimum wear is therefore 0.049 mm.

To further verify the results developed of the micro-punch process as shown in Table 3. The final results were compared with another corresponding experiment data. Based upon the results of this paper, predicted wear comparing with the SA simulation for this optimized punching process; the error is about 4.0%.

Table 3.
The error values of SA method predicted the optimal clearance and min. wear

Item	Value
Punching clearance in BO-side(mm)	0.0105
Punching times	8.67×10^{6}
Predict wear value(mm)	0.035
Experiment wear value(mm)	0.0364
Error (%)	4

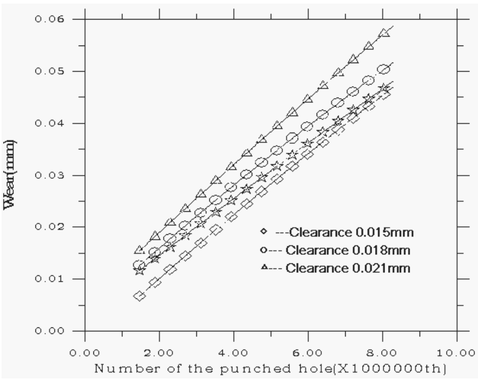

Fig. 5. The relationship between number of the punched hole and wear of punch AO-side

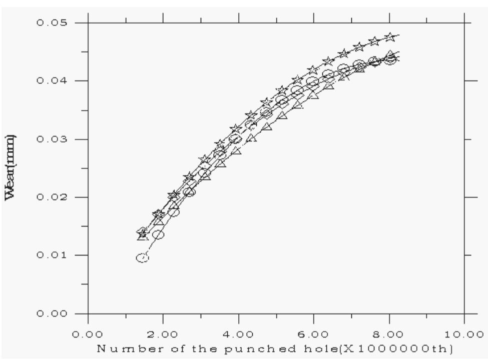

Fig. 6. The relationship between number of the punched hole and wear of punch BO-side

7. Conclusions

In general, clearance plays a key role in both product quality and the service life of dies. A good clearance design not only increases the quality of product manufactured, but also reduces product's burr. As a result, the wear of punches and dies can be greatly reduced and the life expectancy of punching dies increased. More punching times is positively related to bigger wear, while less punching times is related to smaller wear.

In this study, the practical punching processes with different punching conditions were carried out for a set of training data. A trained model exhibited a relationship between service life and clearance of micro punch and die through an abductive network system. The predicted value of wear by abductive network is very close to the actual experimental value, with an error of less than 8%. This result satisfies the required standard for IC factory production.

The abductive network was so precise that engineers only need to choose an optimal input parameter (clearance and punching times) in order to obtain the output parameter (wear) immediately. They are also able to estimate the wear of punches and dies without the need for any punching experiments. Worn punches and dies indicate the end of service life, allowing engineers to replace them before they crack. It is a great convenience for engineers to focus on both accuracy of products and service life of punches and dies, thus improving production efficiency.

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