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A Neural Network Strategy for Process Optimization

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Abstract: Designing high-quality products/processes at low cost leads to increasing market share and gaining competitive advantage. Thermoforming of plastic sheets has become an important process in industry because of their low cost and good formability. However there are some unsolved problems that confound the overall success of this technique. Nonuniform thickness distribution caused by inappropriate processing condition is one of them. In this study, results of experimentation were used to develop a process model for thermoforming process via a supervised learning back propagation neural network. An "inverse" neural network model was proposed to predict the optimum processing conditions. The network inputs included the thickness distribution at different positions of molded parts. The output of the processing parameters was obtained by neural computing. Good agreement was reached between the computed result by neural network and the experimental data. Optimum processing parameters can thus be obtained by using the neural network scheme we proposed. This provides significant advantages in terms of improved product quality.

Keywords: Polypropylene Foam, Thermoforming, Artificial Neural Network, Optimal Processing Parameters.

1 INTRODUCTION

Manufacturing strategy has been defined as the adoption of courses of action and the allocation of resources necessary for carrying out the goals [1]. Such a broad definition of strategy covers a multitude of decisions how can manufacturing contribute to the competitive advantage of this business. Manufacturing objectives cover such things as cost, quality, delivery and flexibility and usually there are trade-offs between them. Trade-off decisions are also required in a number of key areas in order to support the manufacturing objectives. Production planning/control and product design/engineer- ing are identified within the decision areas. These basic ideas (trade-offs and consistency of objectives/policies) have formed the foundation from which the current understanding of manufacturing strategy has developed.

Designing high-quality products/processes at low cost leads to increasing market share and gaining continuous customer loyalty. Robust design combines the experimental design techniques with quality loss consideration, is an engineering approach of quality improvement that seeks to obtain a lowest cost solution to the product design specification based on the customer's requirement. There is a significant amount of ongoing research in the area of the thermoforming [2] process in industry due to its low cost and good formability. However there are some unsolved problems that confound the overall success of this technique. Nonuniform thickness distribution caused by inappropriate processing condition is one of them. In this study, results of experimentation were used to develop a process strategy for thermoforming process via a supervised learning back propagation neural network. In the process, a thick sheet is clamped in a frame and is heated to a temperature well above its glass transition temperature such that it becomes rubbery and soft. It is then placed over a mold and is stretched to take on the contours of the mold, either by a plug assist or a differential pressure.

An inverse back-propagation neural network [3-5] was proposed to model the thermoforming process of polyethylene terephthalate (PET) materials and to predict the optimum processing parameters. The network inputs included the thickness distribution at different positions of molded parts. The output of processing parameters was obtained by neural computing. The network training was based on 47 sets of training samples and the trained network was tested with 10 sets of the test samples, which were different from the training data. The final goal of this study is to optimize the thermoforming process of PET sheets by using the neural network method, providing significant advantages in terms of improved product quality.

2 EXPERIMENTAL

A neural network is a computer system, which mimics the structure of human brain and imitates intelligent behavior [6]. It consists of many simple and highly connected neurons (processing elements or nodes), and processes information by its dynamic-state response to external inputs. It can deal with the problems of highly dimensional and nonlinear systems. The parallel distributed processing of the neural networks promises high computation rates provided by the massive parallelism, a greater degree of robustness or fault tolerance due to adapt and to continue to improve performance. The learning is based on samples, so it is especially suitable for the complicated process with a nontransparent mechanism. Therefore, neural networks, as one of most active branches of artificial intelligence in recent years, have been widely used in the process industries, including fault diagnosis and pattern recognition, process control and optimization, system modeling, and on-line measurement and prediction.

The earliest embryonic form of neural network was presented by a computer scientist named Rosenblatt (1958). Later, Minski and Papert (1969) claimed that the learning ability of ANN was very limited and could not even complete the basic functions of Exclusive OR gate. Hopfield and Tank (1985) proved that as long as appropriate network architecture was established and calculation of error function was defined, the network would be able to quickly obtain a good approximate solution. Rumelhart and McClelland (1986) were the first researchers to present the back-propagation network, and after that, ANN started to be widely applied to engineering fields such as physics, electronics, electric machinery, automatic control and so on [4,5].

A neural network is composed of many artificial neurons and links and can be formed into various types of network models. With learning, reasonable inference can be generated, making it very suitable to solve complex problems. Meanwhile, its nonlinear model is of high accuracy and has the advantage of accepting logical, numerical, order-relevant and order-irrelevant input, allowing for a wide range of adaptability and application. Currently, the most widely applied model is the Back-propagation Neural Network, a type of supervised learning network that is based on the concept of the gradient descent or steepest descent method, which minimizes the error functions of actual output and expected output. With the addition of hidden layers and the use of smooth and differentiable transfer function, the formula for the weight of the correction network can be derived from the gradient descent or steepest descent method.

In Fig.1 depicting the basic structure of ANN, $X=(x_1, x_2,\ldots, x_n)$ is the input layer, and in each layer, the link of neural networks W_{ij} stands for the weight required for Unit *j* in one layer to move to Unit *i* in the previous layer. The functions of each layer are detailed as follows.

1. Input Layer: This represents the input variables of the network, and the numbers of processing units depend on the research problem, with the application of the linear transfer function, i.e., $f(x) = X$.
2. Hidden Layer: This represents the interaction between the processing units, and there is no standard method by which to determine the number of processing units. Generally, the best number can be decided by means of Trial and Error Method. Normally the number of hidden layer units is between (the number of input layer units + the number of output layer units)/2 ~ (the number of input layer units + the number of output layer units) x 2. In addition, due to the application of nonlinear transfer function, the network can either be more than one hidden layer or be designed to be without a hidden layer.
3. Output Layer: This represents the output variables. The number of processing units depends on the question, and the nonlinear transfer function is also used.

(Fig. 1 The structure of ANN)

An "inverse" neural network was proposed for system optimization in this study. Most neural networks use processing parameters as the inputs and molded product qualities as the computed outputs. We allocated inversely, the inputs and outputs in our model; i.e., assigned the product qualities as the inputs and the desired processing parameters as the outputs. The input variables in this research are the measured thickness profiles of molded parts at six different positions. The output variables include five different processing parameters: temperature of the heating pipe, vacuum pressure, plug moving speed, plug displacement, and thermal conductivity of the plug material. Thirteen nodes were selected for the hidden layer, which corresponds to two times the number of input variables plus one; i.e., the network 6-13-5 (six nodes in the input layer, thirteen nodes in the hidden layer, five nodes in the output layer) was chosen as the final structure, using a sigmoid function as its transfer function. By adopting an inverse neural network, we are able to determine the optimum processing parameter sets for the desired thickness profile of the parts.

3 RESULTS AND DISCUSSION

In this report, a model based on the ANN approach was used to predict an optimum setting of thermoforming parameters to achieve the optimum qualitative responses of polypropylene foams. Using the "inverse" neural network proposed in this study, we were able to predict the optimum set of processing parameters for the inputted part thickness distribution. In this study, forty-seven sets of data were used as training samples and the trained neural network was tested by 10 sets of data, which were different from the training samples. The network inputs included the thickness distribution at different positions of molded parts, and the output of the processing parameters was obtained by neural computing. To facilitate the training process, numbers were assigned to different plug materials: 1 for wood covered with woven blanket, 2 for a wood plug, and 3 for a phenol formaldehyde plug. The whole training procedure involved adjusting all weights on connections of the network according to the learning rule. The iteration continued until the computed outputs reached the required precision of agreement to the actual outputs. The test results are in Figs. 2-4 [7]. The results show good agreement to the actual measurement, except for the plug material sample in Fig. 4.

The most valuable result of this research is not only a development of a practical neural network for the thermoforming process of plastic sheets, but also a technique which has been proved to be suitable for modeling and predicting of the thermoforming process. It is valuable for the optimum control of the process and of practical significance to advanced thermoforming processes. Further research is suggested to consider the effect of different thermoplastic materials and assisting plug’s geometry and temperature, because they may influence significantly the performance of the thermoforming of thermoplastic materials.

4 CONCLUSIONS

This study has proposed an inverse neural network model to predict optimum processing conditions. The network inputs included the thickness distribution at different positions of molded parts. The output of the processing parameters was obtained by neural computing. Good agreement was reached between the result computed by the neural network and the experimental data. By using the neural network strategy, one is able to optimize the thermoforming process of PET sheets, providing significant advantages in terms of improved product quality.

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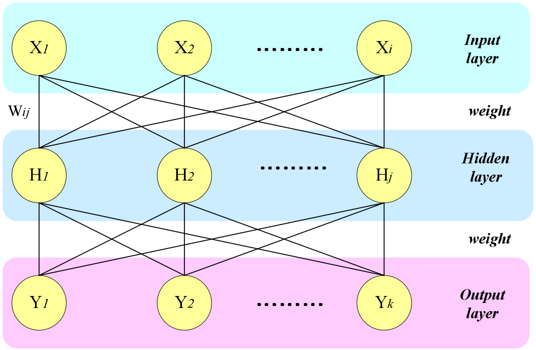

Figure 1 The structure of ANN

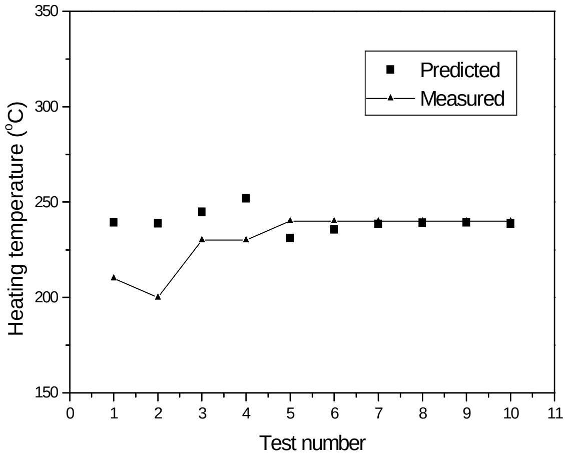

Figure 2. Comparison of predicted heating temperature to actual measurement [7].

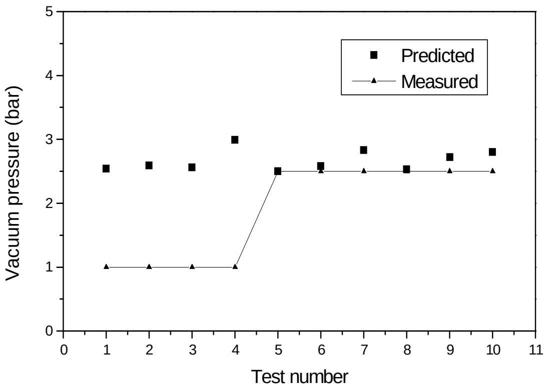

Figure 3. Comparison of predicted vacuum pressure to actual measurement [7].

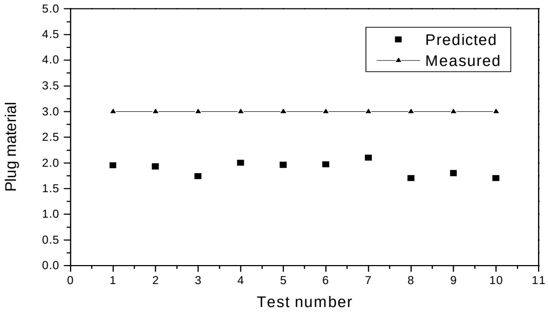

Figure 4. Comparison of predicted plug materials to actual measurement (1: woven blanket, 2: wood, 3: phenol formaldehyde) [7].

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