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Modelization of Three-layered Polymer Coated Steel-strip Ironing Process Using a Neural Network

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Abstract. An alternative to the traditional can manufacturing process is to use plastic laminated rolled steels as base stocks. This material consist of pre-heated steel coils that are sandwiched between one or two sheets of polymer. The heated sheets are then immediately quenched, which yields a strong bond between the layers. Such polymer-coated steels were investigated by Jaworski [1,2] and Sellés [3], and found to be suitable for ironing with carefully controlled conditions.
A novel multi-layer polymer coated steel has been developed for container applications. This material presents an interesting extension to previous research on polymer laminated steel in ironing, and offers several advantages over the previous material (Sellés [3]).
This document shows a modelization for the ironing process (the most crucial step in can manufacturing) done by using a neural network

Keywords: Polymer coating, steel, neural network, can, manufacturing.
PACS: 47.85.mb , 84.35.+I

INTRODUCTION

Beverage cans are no longer simply homes for carbonated soft drinks or beer. Cans are used today for energy drinks, coffee and even wine. One hundred billion beverage cans are produced each year in the United States alone. The economic competitiveness of the industry is fierce and the manufacturing processes involved are extremely reliable. Can makers often calculate the cost of a can to millionths of a cent because of the high production volume. Process modifications which increase or decrease the cost per can even marginally can have a significant impact on the industry.

Essentially all beverage containers in the United States are manufactured from aluminum, whereas beverage cans made in Europe and Asia are approximately 55 percent steel, and 45 percent aluminum alloy. Food containers are still mostly made from steel stock in both Europe and North America.

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Modern food and beverage cans are either two- or three-piece construction. An attractive alternative to the traditional manufacturing process is to use thermoplastic or thermoset laminated rolled steels as base stocks. Such materials consist of pre-heated steel coils that are sandwiched between one or two sheets of polymer. The heated sheets are then immediately quenched, which yields a strong bond between the layers.

It should be noted that the polymers are only useful if they maintain their integrity during forming - any fractures or delamination can cause container corrosion and content spoilage. A cursory review of the metal forming steps in can making results in identification of ironing as the critical operation for polymer coating survivability. In ironing, the pressures are extremely large, the strains and strain rate are very high, and new surface is manufactured from the sheet bulk.

A novel multi-layer polymer coated steel has been developed and is being considered for container applications. This material presents an interesting extension to previous research on polymer laminated steel in ironing.

There has been a recent growing interest in applying artificial neural network (ANN) to engineering fields for solving complex problems. In this paper, the neural network model has been developed to predict the lowest force and the best surface quality in ironing. The neural network has been trained with 46 sets of different process parameters. The predicted results have then verified with experimental values.

MATERIAL

The novel three-layered polymer coating considered in this paper is illustrated in Figure 1, and has the following characteristics:

- A three-layer system can be placed on both the punch and die sides of the sheet.
- The layer bonded to the metal substrate is referred to as the Tie layer, followed by the Bulk layer and finally the Top layer. A typical thickness ratio for the tie/bulk/top layers is 1:3:1, with typical overall thickness of 12.5-25 µm.
- The layers can be adjusted to meet specific customer requirements

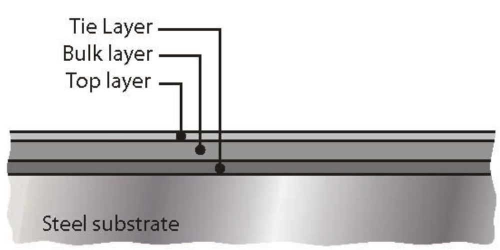

FIGURE 1. Illustration of the three-layered polymer-coated steel used in the experiments

There is significant flexibility in formulating this material, and many combinations of chemical and mechanical properties can be achieved.

EXPERIMENTAL PROCEDURE

The experimented material displayed good ironability for a number of conditions. A design-of-experiments matrix was prepared using the commercial software package Stat-Ease, and involved varying the die angle, speed, reduction in thickness and tooling temperature. Since the experimental matrix on the white side was conducted first, and the effect of opacity was not expected to affect ironability, a reduced experiment matrix was completed on the clear side. Experiments can result in successful ironing or the removal or shaving off of one or more polymer layers.

It should be noted that these results are pertinent to the die-workpiece interface; the punch-workpiece interface demonstrated good survivability under all conditions.

A Surface Quality Factor (SQF) was used as a qualitative measure of surface appearance after an experiment. The Surface Quality Factor has been defined as:

0. Shaving of the polymer coating.
2. Partially survived/partially shaved coating; surviving coating displays significant roughening.
4. Coating is partially intact, with local defects and roughening.
8. Intact coating with minor surface defects.
10. Successful ironing; intact coating with superior surface finish.

Representative examples of these Surface Quality Factors are given in Figure 2. It should be noted that shaving (surface quality factor of 0) still involved one or more polymer layers adhering to the steel as described below.

The SQF is a qualitative measure, based on visual appearance of the surface. In general, an SQF of 8 or 10 represents a sample that is acceptable for ironing applications. These polymer coatings maintained their integrity and would satisfy the design requirements of protecting the can wall material and contents from each other. An SQF of 0-4 indicates a surface with serious defects that are clearly unacceptable for functional reasons. While a qualitative measure, it should be noted that there is a clear distinction between the shaved or partially-shaved surfaces (with an SQF of 0-4) and a successfully ironed surface (with an SQF of 8-10). When damage to the polymer surface occurred, it was rarely localized, but instead occurred over the entire specimen surface.

Also, the surface quality that is seen in Figure 2 could most likely be improved if the tooling surface finish was improved. The titanium carbide inserts used for ironing did leave noticeable scratches in some specimens. The inserts were produced by diamond polishing, but were not refinished for the subject research in order to save time and expenses; it is felt that surface quality factors of 8 could probably be improved with better tool surface finish.

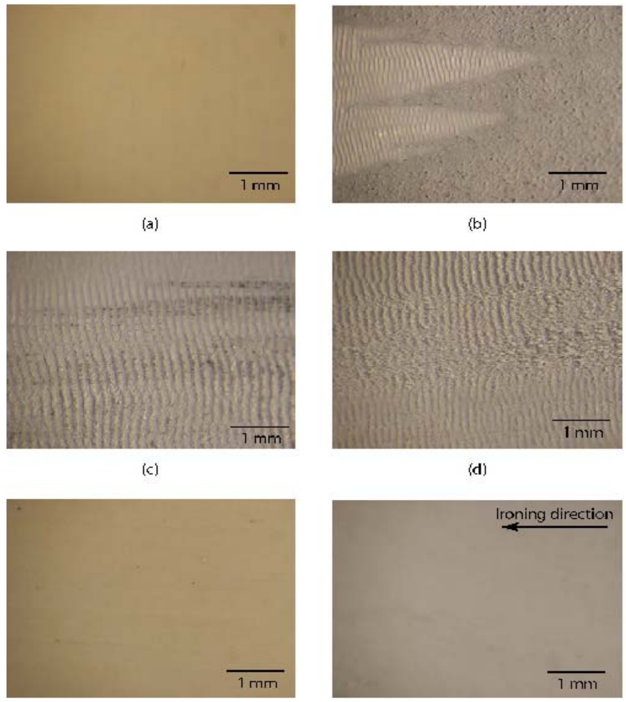

FIGURE 2. Representative surface microphotographs of the test specimens. (a) As-received; (b) surface quality factor (SQF) =0; (c) SQF=2; (d) SQF=4; (e) SQF=8; (f) SQF=10

ARTIFICIAL NEURAL NETWORK MODELIZATION

Experiment planning is a method used to organize the experiments and found, in a process, what variables are significant, how they interact among them, and what is the best condition to optimize the process. This provides a design of experiments (DOE) containing the factor identification (process variables) that produce changes in output variables (variable result of process). Between the different methods that exist to develop designs of experiments (factorial designs, fractional factorial designs, regression surface response, designs by blocks, d-optimal...), d-optimal technique has been adopted.

TABLE 1. Input variables.

Variables		Units
Die angle	DA	º
Punch speed	PS	m/s
Reduction	RD	%
Temperature	T	ºC

The four process variables shown in Table 1 have been used for DOE realization. The variable levels are then shown in Table 2.

TABLE 2. Process variable levels

Process variables		Levels				
Die angle	º	2	4	6	8	10
Punch speed	m/s	0.5	0.75	1		
Reduction	%	5	10	15	20	
Temperature	ºC	25	100			

Neural networks are composed of processing elements or nodes. These are connected among them through a path that allows a high degree of parallelism between their functions. Each node is only able to perform a simple operation. In order the network can work properly, it is necessary a learning period, which is achieved by assigning correct weights to each of the node connections to minimize the relative output error. We will consider that the network is trained when the weights have reached an optimal value, and have achieved the minimum possible error.

The output of a neuron or processing element is a non-linear function of its inputs. Once the network is trained, if new entries are introduced, then the network automatically predicts values for the respective outputs.

To achieve the proposed objective, a neural network has been built with the help of a special software. The training has been done through the use of the algorithm Back Propagation (BP), on the basis of the random establishment of initial weights between the neurons connections.

The optimal neural network (Figure 3) design has been achieved after 76315 training cycles, and consists of an input layer with four process variables (Table 1), two hidden layers with 7 and 8 neurons, and finally, a layer of five considered output (Table 3). There are 342 connections in total. The average error is $3.13 \cdot 10^{-3}$ (Figure 4).

TABLE 3. Output variables.

Variables		Units
SQF	SQF	
Longitudinal Roughness	LR	μm
Transversal Roughness	TR	μm
Radial Force	RF	N
Ironing Force	IF	N

An analysis of sensibility has been made and shows us how an exit variable changes when the input variables are modified. All the input variables are set to average values and the incremented from low to high values. The results obtained are shown on Table 4.

TABLE 4. Sensitivity analysis.

Process variables		Sensitivity
Die angle	º	0.155
Punch speed	m/s	0.059
Temperature	ºC	0.003
Reduction	%	0.001

Die angle is the most influent input variable as can be seen. Punch speed is also important. This is consequent with experimental data.

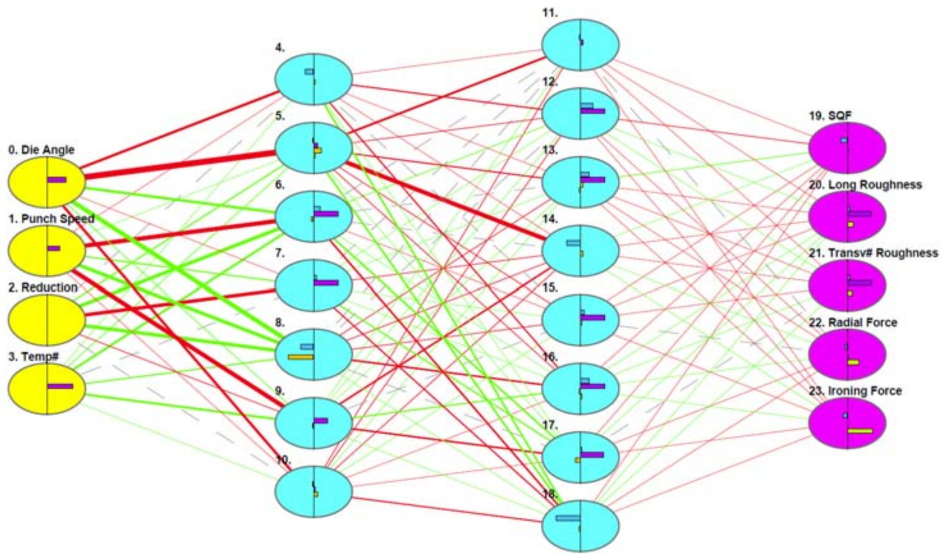

FIGURE 3. The optimal neural network found

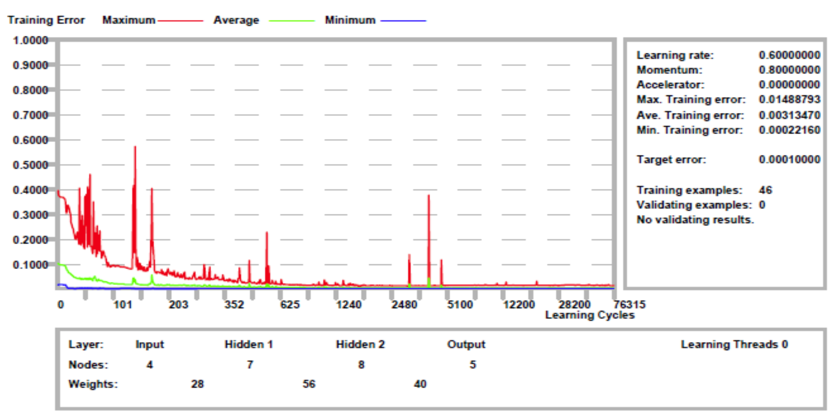

FIGURE 4. Learning cycles and final training error achieved.

CONCLUSIONS

It has been experimentally shown the validity of the model presented in this work, obtaining coincident results for both methods (theoretical modelization and experimental data), proving the statements held in this paper.

Even the described model has been developed using 4 process variables, it is possible to extend it to the set of process variables that are needed to be considered, though it must be taken into account that the selected variables must be included in the process simulation. With this alternative it is possible to extend the definition of the proposed indicators or include new indicators that have a good adaptation to the effects that are studied.

Likewise, this optimization methodology offers many possibilities for any geometry and that guarantees that its field of use can be extended to an endless number of complex geometries, particular cases...

The experimental results obtained reveal that the evaluated effects on the pieces follow the tendency that the indicators show, and at the same time, validate the optimization criteria considered so as to keep the most suitable values for the measured parameters.

ACKNOWLEDGEMENTS

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