

# ANALYSIS OF A POLYMER-COATED STEEL FOR FOOD CAN MANUFACTURING

Miguel Angel SELLES<sup>1</sup>, Elena PEREZ-BERNABEU<sup>2</sup>, Rafael PLA-FERRANDO<sup>3</sup>, Samuel SANCHEZ-CABALLERO<sup>4</sup>

<sup>1</sup>Universitat Politècnica de Valencia, maselles@dimm.upv.es

<sup>2</sup>Universitat Politècnica de Valencia, elenapb@eio.upv.es

<sup>3</sup>Universitat Politècnica de Valencia, rpla@mcm.upv.es

<sup>4</sup>Universitat Politècnica de Valencia, sasanca@dimm.upv.es

**Abstract**—A new polymer coated steel has been developed and is being considered for food-container applications. This material presents an interesting extension to previous research on polymer laminated steel in ironing. A design-of-experiments matrix has been prepared using the commercial software package Stat-Ease, and involved varying the die angle, speed, reduction in thickness and tooling temperature. Formability data has been obtained both through experimentation and theoretical modelling with upper bound methods.

**Keywords**— Ironing, solid lubricant, polymer coating, food.

## I. INTRODUCTION

ACTUAL food cans are either two- or three-piece construction. The metal forming processes involved in can manufacture is shown in Fig. 1. A circular blank is punched from rolled sheet stock, redrawn, ironed in two or three stages, domed, necked, filled and seamed. In between the doming and necking operations, the cans are placed in a wash/coat process which removes the residue lubricants from metal forming (which are invariably toxic in large amounts) and applies a base coating to the metal. The cans are then subjected to one or more spray operations to provide a safe food/drink contact surface and to prevent chemical interactions between container and contents. The polymer also can be applied to the exterior to serve as a permeable coating suitable for further decorating operations. The spray often consists of a polymer resin in a carrier such as methyl ethyl ketone, requiring the carrier fluid to be evaporated, resulting in volatile organic compounds (VOC) which may not be exhausted into the atmosphere but instead must be burned to form more benign products. VOC production is a serious concern of can makers, and has received considerable legislative attention in the past years. 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.

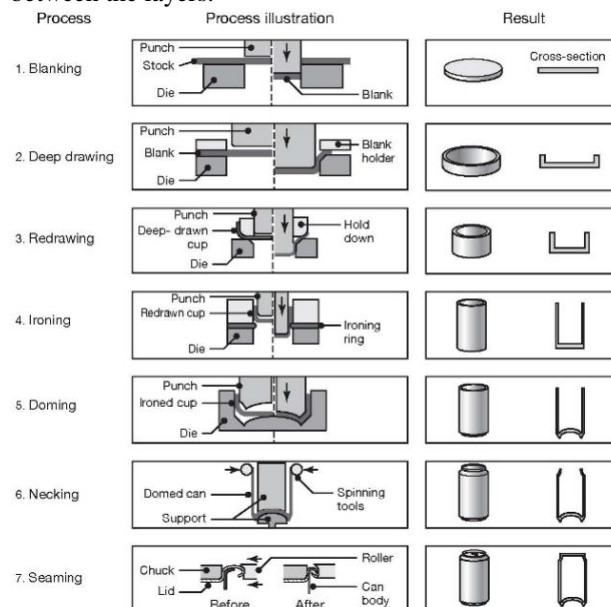


Fig. 1. The metal forming steps involved in can manufacture, [6]

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, and this paper presents a preliminary evaluation of the new material.

A strip ironing simulator, shown in Fig. 2, was developed for metal forming research at the University of Notre Dame, USA. A workpiece in the form of a sheet-

metal strip approximately 25 mm. in width is clamped to a hydraulically-driven punch and pushed through a die opening less than the strip thickness, which directly simulates the ironing process. A 30 hp motor powers a hydraulic pump, so that that ironing speeds of up to 2 m/s are possible.

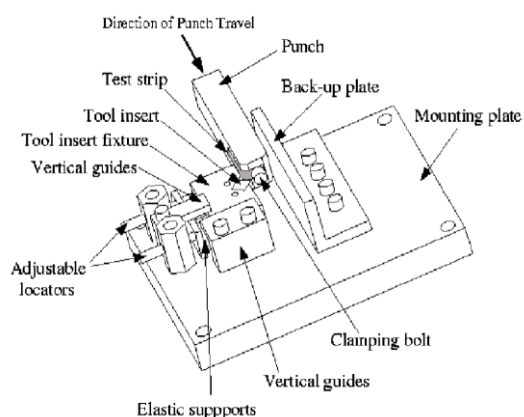


Fig. 2. Schematic illustration of the ironing simulator

The ironing reduction can be modified by adjusting locator screws. Ironing and normal forces are measured by strain gauges bonded to elastic supports for the tooling fixture, and the thickness of the strip before and after ironing is measured with strip micrometers. A tooling insert can be quickly changed to allow for various materials, die angles and land lengths.

Previous research efforts have been performed using the strip ironing simulator, including work on polymer laminated steels. Jaworski and Schmid [1] demonstrated that laminated polymer-coated sheet steels can be used as ironing stocks. Experiments found that low die angles results in a successful ironing operation, while large die angles result in shaving of the polymer film off of the steel. Kawai et al. [2] and Kenny and Sang [3] also developed an experimental apparatus to measure the friction coefficient on the die surface in the strip ironing process. A metal strip combined with a back-up plate (punch) was pulled through a bearing and a die. Ironing travel, reduction and lubrication were varied to study their effects on the die friction coefficient, surface appearance and galling.

Van der Aa et al. [4] used a finite element model to simulate the wall ironing of polymer coated sheet metal. They verified their results with a plane strip ironing set-up. For those results, they found that a shear deformation occurs in the aluminium sheet metal rather than in the polymer coating, which apparently only reduces in thickness.

Appleby et al. [5] used transparent dies in a plane strain strip drawing apparatus in order to measure die-interface velocities. In this way, incremental displacement boundary conditions were obtained as input in a FEM analysis.

Jaworski et al. [6] investigated the friction and forming

characteristics of two steels, one with a tin plate and the other with a chrome plate and polyester laminated coating. Huang and Schmid [7]-[8] examined the effect of heat in ironing a polymer coated steel workpiece. This research was intended to simulate the proposed use of polymer coated steels without any coolant, and where the tooling temperature is higher than room temperature. Such circumstances arise commonly in ironing, due to the heat dissipated through friction and plastic deformation in the process. They also demonstrated that ironing without a coolant such as water is not likely to be feasible because of the significant reduction in material survivability.

Kampus and Nardin [9] used the theory of plasticity to model the ironing process, making an ironing workability diagram to describe the stress-strain state. They applied this model to production of cups with non-uniform wall thickness, where observed with the help of a FEM software the action of the superimposed forces. The theoretical model and experiments showed that the maximum strain can be increased by up to 40% with the use of a superimposed force.

## II. EXPERIMENTAL INVESTIGATION

Surface Quality Factor (SQF) was used as a qualitative measure of surface appearance after an experiment. Values of the Surface Quality Factor are summarized in Table I.

TABLE I  
 SURFACE QUALITY FACTOR VALUES

Value	Description
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 Fig. 3. 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.

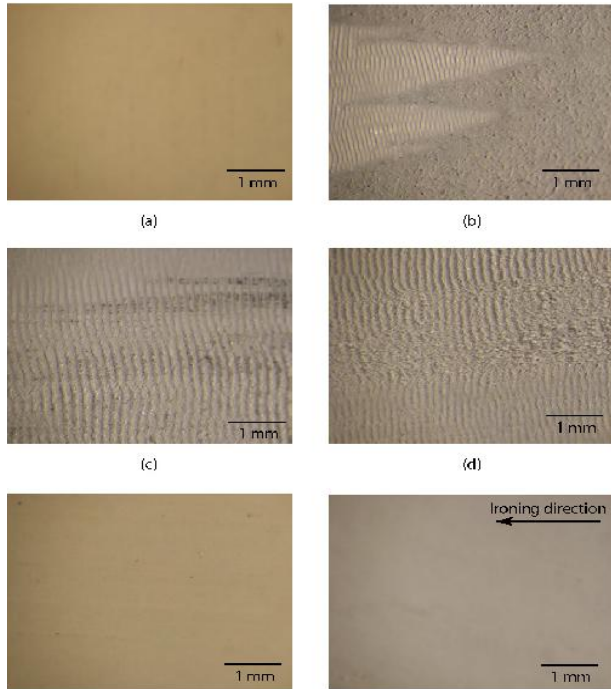


Fig. 3. Representative surface microphotographs of the test specimens. (a) As-received; (b) surface quality factor (SQF) =0; (c) SQF=2; (d) SQF=4; (e) SQF=8; (f) SQF=10.

Also, the surface quality that is seen in Fig. 3 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.

### III. THEORETICAL MODELIZATION

Two possible results have been considered as ironing consequence on the workpiece: successful ironing and shaving. In this case, the workpiece is damaged and it's not appropriate. The steel base is coated by three polymer layers, and if the workpiece is damaged in the ironing, one of these consequences will occur:

- 1) *Damage only at the top polymer layer.*
- 2) *Damage at both top and bulk polymer layers.*
- 3) *Damage at the three polymer layers.*

Two models have been developed using the Upper Bound Method: one for successful ironing and the another one in case of shaving. The power needed to damage the tie and bulk layers is always higher than the power needed for produce damage at the top layer. For

this reason it has been modelled only the case where it's produced damage at the top layer.

The two corresponding upper bound models developed are characterized by some simplifying assumptions. As discussed above, both the coatings and workpiece are assumed to have no strain hardening or strain rate effects, and sticking frictions and plane strain conditions are invoked. The materials are considered rigid, perfectly plastic solids with constant shear strengths, which is necessary for deformation to occur in well defined shear planes. But however, a polymer seldom behaves as a perfectly plastic material, nor does it typically deform along discrete planes. However, it is felt that the use of a reasonable amount of deformation planes will improve the accuracy of the power estimates.

In the models done, the coating effective shear strength,  $k_i$ , is specified as fraction of the workpiece shear strength,  $k_p$ .

Each frictional interface in the system has a unique friction factor.

Fig. 4 depicts a velocity discontinuity field class for successful coated ironing using a three-layer polymer coated steel. The diagram is not to scale, and friction factors remain as defined above. Plane G-Die is assumed to exist along the entire land length.  $m_i$  are the respective friction coefficients;  $t_{xi}$  is the initial thickness for each layer, while  $t_{xf}$  is the final thickness of each layer just after ironing; and  $V_p$  is the punch velocity.

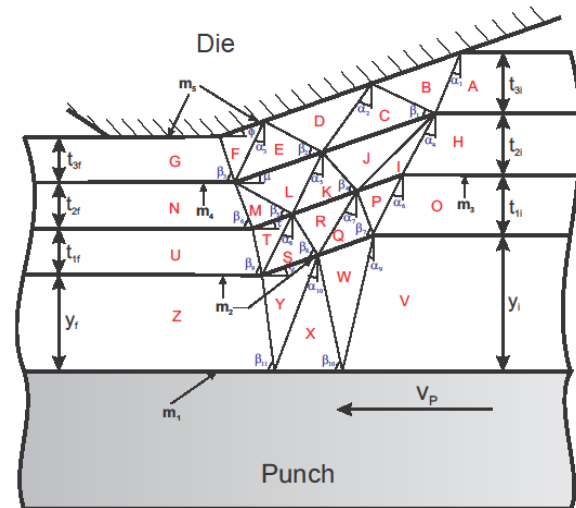


Fig. 4. Velocity discontinuity field for a successful ironing

### IV. RESULTS

As shown in Fig. 5, the surface quality factor is very high at die angles around 6 degrees or lower, but shaving occurs with greater frequency as the die angle increases. Also, it can be seen in Fig. 5, although the difference is negligible, that the SQF is slightly better at high temperature.

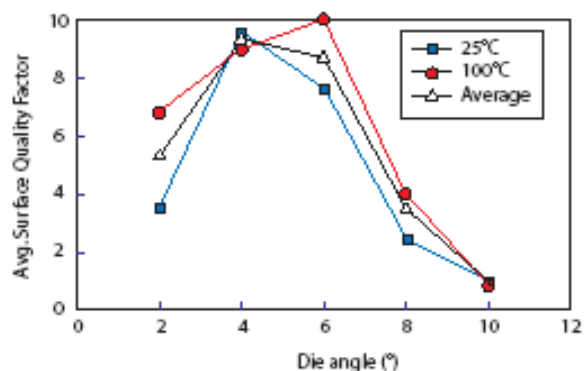


Fig. 5. Average surface quality function for the material as a function of die angle.

The process parameters were evaluated with respect to their importance on surface quality factor (analysis of variance). The results are summarized in Table II. As can be seen, the die angle was the most important variable within the range of variables examined. This is consistent with Jaworski and Schmid [2].

TABLE II  
 ANALYSIS OF VARIANCE RESULTS

Variable	Clear polymer (sum of squares)	White polymer (sum of squares)
Die angle	59.52	481.59
Ironing speed	5.36	10.75
Reduction in thickness	0.024	13.3
Temperature	0.024	19.4

Speed had a minor effect, with higher speeds leading to better ironability. This is consistent with strain rate effects on polymer properties; in previous tests, a stronger polymer was less likely to shave and more likely to iron properly.

#### V. CONCLUSIONS

Formability data has been obtained both through experimentation and theoretical modelling with upper bound methods. The three-layered polymer coated steel can result in a material with high ironability. Based on the research performed, we conclude:

- 1) *The polymer laminate coated steel displayed good formability on the punch side of the ironing operation. This is significant, in that this is the container interior in most ironing operations, and suggests that the concept of*

*using polymer laminated steels as ironing basestocks is a sound strategy for reducing VOC emissions.*

- 2) *Ironing die angle is the most important manufacturing process variable; and good ironability is encountered at die angles around six degrees and lower. Higher die angles lead to shaving of the polymer coating.*
- 3) *Ironing speed had a minor effect on ironability, with increased ironability at higher speeds.*
- 4) *Shaving, when present, usually occurred between the tie layer and bulk layer or the top and the bulk layers at the conditions examined. The tie layer always survived ironing for the conditions examined.*
- 5) *The behavior of the polymer was unchanged whether the tests were performed at room temperature or at 100 degrees.*
- 6) *The two theoretical models allow examining the influence of material parameters, and it's possible to give insight into how to design a material that irons well.*

#### REFERENCES

- [1] Jaworski, J.A. and Schmid, S.R., "Survivability of laminated polymer lubricant films in ironing", *Tribology Transactions* 1 (1999), pp. 32-38
- [2] Kawai, N. and Nakamura, T. and Dohda, K., "Development of anti-weldability test in metal forming by means of strip-ironing type friction testing machine", *Journal of Engineering for Industry* 104 (1982), pp. 375-382
- [3] Kenny, L.D. and Sang, H., "Effect of particles on scoring and friction in ironing", *Metal Transfer and Galling in Metallic Systems* (1986), pp. 117-130
- [4] Van der Aa, H.C.E. and Van der Aa, M.A.H. and Schreurs, P.J.G. and Baaijens, F.P.T. and Van Veenen, W.J., "An experimental and numerical study of the wall ironing process of polymer coated sheet metal", *Mechanics of Materials* 32 (2000), pp. 423-443
- [5] Appleby, E.J. and Ly, C.Y. and Rao, R.S. and Devenpeck, M.L. and Wright, P.K. and Richmond, O., "Strip drawing: A theoretical-experimental comparison", *International Journal of Mechanical Science* 26 (1984), pp. 351-362
- [6] Jaworski, J.A. and Schmid, S.R. and Wang, J.E., "An experimental investigation of the survivability and friction characteristics of tin-coated and polymer-laminated steels", *Transactions of the ASME, Journal of Manufacturing Science and Engineering* 121 (1999), pp. 232-237
- [7] Huang, C. H. and Schmid, S. R. and Wang, J.E., "Thermal effects on polymer laminated steel formability in ironing", *Transactions of the ASME* 123 (2001), pp. 225-230
- [8] Huang, C. H. and Schmid, S. R., "Temperatures in ironing of polymer-coated steels", *SME Technical Paper* 253 (2001)
- [9] Kampus, Z. and Nardin, B., "Improving workability in ironing", *Journal of Materials Processing Technology* 130-131 (2002), pp. 64-68