Corus Research Development & Technology has recently developed Le Carré food can. This can has won several awards (Can of the Year Award 1999 and Gouden Noot Award 2000), due to its attractive and remarkably efficient design. One of the critical points in this development has been the seam design. This paper explains the role played by computer simulation in the redesign of Le Carré can to achieve a quality seam.

ABAQUS/Explicit has been used to simulate the seaming process, a very complex and highly non-linear sheet metal-forming process with no positive guiding, where contact interactions are of paramount importance. The simulation methodology has been refined by comparison to real tests. Once tuned, the simulation methodology has helped to understand the seaming process in depth, recommend a new design and validate it through computer pre-test simulation. Pre-test simulation has revealed extremely useful as a tool to avoid time consuming redesign loops and accelerate market presentation of Le Carré redesigned can.

1. INTRODUCTION

1.1 Double Seam Overview

Around one billion of metal cans are closed everyday in the world. Despite the maturity of the industry, the innovation quest is particularly active. Today the packaging industry is in need both to develop newer and more attractive can shapes and to use thinner and higher-temper sheet material. Due to the very high standards set by food cans on food safety and shelf life, closing (seaming) these new can designs presents real difficulties and is a hazard to can innovation.

Double seaming process consists of two operations: 1st operation or hook forming and 2nd operation or ironing. First and second operation seaming rolls orbit around the perimeter of the can to produce the seam. See figure 1.

Seam quality is critical in food cans because, if the seam is not correct, air and micro-organisms could go through the seam into the can and the bacteria cause food spoilage and poisoning. In order to prevent risks, can seam section parameters, specially the overlap (see figure 2) must fulfil specific control values.

The key factor regarding seam quality, directly related to seam section parameters, is the shape of wrinkles after the 1st operation. If wrinkles are very sharp and concentrated, they will not be properly ironed out in the 2nd operation (see figure 2). Consequently, a good can design regarding
seam quality must lead to smooth and distributed wrinkles after the 1st operation, so that these are ironed out in the 2nd operation and the resulting seam overlap is adequate to avoid air entrance.

Idom Advanced Analysis Division has developed a computer simulation methodology focused on accurately predicting wrinkle formation after the 1st operation and determining seam section parameters.

1.2 Le Carré Seam Project
Corus Research Development & Technology has recently developed Le Carré food can (see figure 3). This can has won several awards (Can of the Year Award 1999 and Gouden Noot Award 2000) due to its revolutionary, attractive and innovative square shape, which at the same time saves 20% space and, due to the use of thinner materials, attains up to 15% material reduction as an important environmental achievement.

Concerning the seam development, initially a standard seam design for non-round cans commonly used with thicker and softer tinplates was projected. But this design proved to be inadequate for the thin and high-temper materials of the Le Carré can. Therefore, it has been necessary to accomplish a complete reengineering of the seam design. This work, named Le Carré Seam Project, has been undertaken by an industrial team consisting of Corus, Sommetrade and Idom.

The project has been structured in three successive phases:
- Phase 1: Seaming tests, performed to analyse the seamibility of the original can and to support the tuning of the simulation methodology.
- Phase 2: Simulation methodology development to set up a tool that may serve to assess new seam designs.
- Phase 3: Redesign specifications and pre-test validation by computer simulation targeted to obtain a good seam for Le Carré can.

2. TESTS
Two have been the objectives of the seaming tests performed on the original design of Le Carré can: 1) to conduct a seamability study of the original design and 2) to support the computer model tuning and validation.

Tests have been carried out manually in a modified semiautomatic machine. Plunge method, consisting in a single orbit of the operation roll at the nominal offset, has been used instead of the classical progressive attack technique, which consists in several passes of the operation roll with decreasing offsets. Whilst progressive attack is extensively used for round cans, plunge method leads to better results in non-round cans.

Up to seven different batches of the Le Carré original can—with different tinplates for can body and can lid— and up to five samples of each batch have been tested in order to perform the seamability study. It has been clearly confirmed that the harder and the thinner the tinplate is, the sharper the wrinkles are. In any case, even the best results have not been good enough for a commercial seam.
3. SIMULATION METHODOLOGY DEVELOPMENT

3.1. Finite Element Model

At this stage of the project, the aim has been to develop a simulation methodology that emulates correctly enough the seaming process of the original design of Le Carré can so that new designs could be virtually tested in the future. Among all the batches tested, one has been chosen for the simulation (see table 1). Test results have been used for the tuning of the finite element model.

Can seaming process consists basically of two operations. During first operation the lid and body hooks are formed. These hooks will be ironed out by the second operation roll. The seam quality is determined by certain seam section parameters and specially by the aspect of the unavoidable wrinkles. The wrinkles are generated during the hooking formation and, in non-round cans, mainly on the corners of the can. Analysing the wrinkles pattern after 1st operation, it can be predicted whether or not the 2nd operation will lead to an acceptable seam. Hence, only the first operation has been simulated.

ABAQUS/Explicit has been used for the simulation. As previously said, the seaming process of metallic cans is a highly non-linear and very complex sheet metal forming process in which there is no positive guiding of the material. The non linearities refer to large displacements and deformations of can lid and body flanges, material stress-strain relationship − work hardening occurs during seaming− and contact interactions between different parts involved in the process (can lid, can body, chuck and seaming roll). In this context, explicit integration techniques are needed.

Figure 4 shows the finite element model generated for the simulation. Can body and lid have been modeled by 4-node reduced-integration shell elements (S4R), whilst three-dimensional 4-node rigid elements (R3D4) have been used for chuck and roll modeling. Can and chuck models have been restricted to ¼ of the perimeter, taking advantage of the double symmetry of the system, and to the vicinities of the seam section.

Contact interactions have been solved using the default kinematic contact algorithm. Basic Coulomb friction models have been used.

A speed up technique has been applied in order to reduce CPU time. Experience shows that double seaming is a quasi-static process, as similar results are obtained in automatic and manual seamers. Therefore, seaming roll velocity has been increased above the automatic machines nominal velocities, but taking care that it is not as large as to cause dynamic response of the system. This control has been carried out by checking the evolution of energies in the system − checking that kinetic energy is less than 10% of the total energy− and by comparing simulation results for several runs with different roll velocities.

Model tuning. In such a non-linear case the finite element model needs to be tuned in order to obtain a good agreement between simulation and real results. The fact is that there is a large number of phenomena involved in the process and the effect of some of them on the results cannot be accurately evaluated from the beginning. Certain of the actions committed within the tuning process have consisted in simulating friction forces of the lifter by using a “dashpot” element, modifying friction coefficients at the edge of the body flange, checking the speed-up technique, controlling the sliding of the roll, etc. Some others refer to numerical aspects, such as the number
of integration points on a shell element section and the resolution of contact problems derived from the definition of double sided contact surfaces.

**Roll sliding.** During the tuning of the model it has been found more important to avoid possible sliding of the roll than to assign a very accurate value to the friction coefficient between roll and lid sheet. In this sense, rolling conditions have been guaranteed by scaling the inertia of the roll, so that the distance the roll slides when approaching its nominal offset until it starts rolling is equal both in simulation and in reality.

$$I_{\text{simu}} = I_{\text{real}} \left( \frac{V_{\text{real,centre-roll}}}{V_{\text{simu,centre-roll}}} \right)^2$$

(1)

### 3.2. Results of the Simulation: Seam Sections and Wrinkles

Figures 5 and 6 show the definitive results of the simulation. A notable correspondence between simulation and reality is evident in the two main aspects related to the quality of a double seam, which are: 1) seam section parameters and 2) wrinkles aspect on the corner.

Wrinkles characterization has been performed by taking measurements of the lid edge on a horizontal plane. Each wrinkle is defined by three points (a peak and two valleys) and it is characterized by defining two amplitudes and the wrinkle width. The sharpness is measured by the aspect ratio, defined as the percentile ratio between wrinkle amplitude and wrinkle width. The higher the aspect ratio, the more aggressive the wrinkle is.

### 3.3. Understanding the Seaming Process

In adjunct to the prediction of seam section parameters and wrinkles aspect after first operation, ABAQUS/Explicit computer simulation has proved to be a very useful tool for better understanding the double seaming process itself.

A hook opening was observed during tests program; this effect has been also detected by simulation and, moreover, it could be interpreted. General belief was that wrinkles were generated before the roll or exactly while it was passing over. Nevertheless, simulation has shown that, even if they are certainly initiated when the roll is passing, they immediately seem to fade and are definitely formed after the roll has passed. Hence, notably sharp wrinkles formation can provoke the previously mentioned hook opening effect.

Other profitable outputs obtained from the numerical simulation of the double seaming process are, among others: 1) quantification of seaming forces, which could be very useful to feed back the simulation of a seaming machine mechanism and 2) the location of the mathematical rolling point of the roll determines the maximum wear area on the roll profile, which is a relevant information for an appropriate tooling design.

### 4. REDESIGN SPECIFICATIONS AND PRETEST VALIDATION

Redesign preliminary recommendations have been stated based on both theoretical estimations, previous know-how and seaming process understanding derived from computer simulation with
ABAQUS/Explicit. These initial recommendations have been refined and the new design has been finally validated through computer pre-test simulation.

Simulation results for the proposed redesign reveal clear improvements in the seaming with respect to the original design. Figures 6 and 7 testify this point. The excessively sharp and concentrated wrinkles that appeared in the initial design no longer appear in the redesign. Instead, very uniform and distributed wrinkles are formed, which can be ironed out in the 2nd operation. This is the main validation of Le Carré proposed redesign.

The quantitative comparison of wrinkles also assesses the previously mentioned differences between initial design and redesign (see table 4).

Small values of wrinkle width and large amplitudes lead to high aspect ratios in the original design (30% average), corresponding to sharp and aggressive wrinkles.

The improvement is evident in the redesign, for which the average aspect ratio falls down to 11%, hence indicating that the wrinkles are much softer and, therefore, easier to be ironed out by the second operation roll. Furthermore, similar average values of wrinkle width and spacing also indicate a uniform and smooth distribution of wrinkles.

The results are very good, not only concerning the wrinkles pattern, but also referred to the seam sections, which are very uniform all along the perimeter of the can. However, the simulation has been useful once again at this stage, because it has shown the necessity of cosmetic changes: to trim the body flange (-0.15 mm) and to elongate the lid flange in the corner (+0.20 mm). See figure 8. Consequently, the simulation not only validates some redesign recommendations but also helps to improve the seam section parameters previously tests.

With these last changes incorporated, final redesign manufacturing drawings for Le Carré can and tooling have been produced. The new Le Carré can has been presented to the market at IPA 2000, Salón de l’Emballage, Paris.

5. CONCLUSIONS

Seaming simulation methodology developed by Idom Advanced Design & Analysis Division using ABAQUS/Explicit has proved very useful to optimize Le Carré food can. Pre-test simulation has saved Corus Research Development & Technology time consuming redesign loops, being a useful tool for right-first-time can manufacturing.

Furthermore, seaming simulation methodology is not only effective to assess new designs. Simulation of the seaming process helps understanding key factors involved:

- Mechanics of wrinkle formation: when and why exactly sharp and unacceptable wrinkles appear
- Seaming forces influence
- Location of mathematical rolling point of seaming roll: maximum wear area
- Process parameters and roll geometry effects
Both Sommetrade and Corus find this new technique advantageous for their businesses. Sommetrade is involved in using seaming simulation for seaming machine engineering, whilst Corus Research Development & Technology is interested in the technique in order to advise customers (can makers) on optimal material thickness and temper as a function of can shape and seam height.

Understanding the seaming process, such a complex metal forming process, is essential to make it controllable and eliminate uncertainties. Seaming simulation methodology is fundamental to this effect.

References

5. Evaluating a double seam, W.R. Grace & CO: Massachusetts (USA)
6. Recommendation SEFEL nº1 for ‘Non Easy Open’ Steel Ends (NR4 WG2), SEFEL: Bruxelles (Belgium), 1999

TABLES

<table>
<thead>
<tr>
<th>Table 1. Batch used for the computer Simulation</th>
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<tr>
<td><strong>Thickness (mm)</strong></td>
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### Table 2. Wrinkles characterization. Simulation results

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<tr>
<th>Wrinkle number</th>
<th>Ampl 1 (mm)</th>
<th>Ampl 2 (mm)</th>
<th>Width (mm)</th>
<th>Aspect Ratio</th>
<th>Spacing (mm)</th>
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### Table 3. Wrinkles measurements on real sample

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### Table 4. Comparative table. Average values of wrinkles parameters

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FIGURES

Figure 1. Double seaming process

Excessively sharp wrinkles are very difficult to iron out in a 2nd operation:

Figure 2. Seam quality key factors
Figure 3. Le Carré food can

Figure 4. Finite element model
Figure 5. Seam section after first operation. Simulation (computed) results vs. tests (real) results. Agreement between computed and real results far exceeds measurement deviations.

Figure 6. Wrinkles on the corner. Number of wrinkles, shape and distribution coincide both in reality and in simulation.
Figure 7. Proposed redesign: uniformly distributed and smooth wrinkles, easily ironed out.

Figure 8. Cosmetic modifications required: body flange trimmed 0.15 mm (both at straight part and corner for manufacturing reasons) and lid flange elongated 0.20 mm only at the corner.