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A multifactor approach to evaluate the sealing of "smooth-wall" containers for food packaging

T. Monetta *, A. Acquesta, F. Bellucci

Department of Chemical Engineering, Materials and Industrial Production, University of Naples Federico II, Piazzale Tecchio 80, 80125 Napoli, Italy

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ABSTRACT

This work deals with the choice of materials, surface finish and parameters to be considered for the design of the production process of so called "smooth-wall" aluminium containers for food packaging. Evaluating the detachment at the metal/lid interface the following parameters have been considered: (i) the Fe amount in the Al alloy, (ii) the effect of lubricant oil, (iii) the surface "shape" of containers in contact with the lid and (iv) the alloy grain structure. Results obtained suggest that the detachments could be reduced if a low iron content alloy is used. Roughness measurements have highlighted that the surface showing $S_{ku} > 3$ provides a much higher adhesion. Metallographic measurements showed that the use of high iron content alloy results in numerous corrosion spots preventing adhesion between the sealant polymeric film and the aluminium foil. In conclusion: in all over the design of the device a multifactor approach would be adopted: a right combination of alloy composition, "surface shape", lubricant oil and alloy grains dimension, should be considered to avoid failures.

1. Introduction

Due to its characteristics, aluminium and its alloys are used for a wide range of applications. The good formability permits the fabrication of many forms of containers, such as cans, aerosol cans, tubes, wraps, etc. [1]. Aluminium can be painted, lacquered, printed and coated with paper and polymers. It is hygienic, non-toxic and non-tainting, therefore it can be used for pharmaceutical and cosmetic applications. Moreover aluminium packaging provides the perfect protection from light, moisture, oxygen and germs without altering the odour, taste or colour of the content. As such, it is of fundamental importance for food applications [2]. In 1911, Tobler started wrapping its chocolate bars in aluminium foil, including the Toblerone [3]. The heat conductivity of aluminium is excellent. The food stored in aluminium container can be warmed, steamed, baked or grilled directly in the aluminium package, which does not lose any of its protective properties. Foil containers are not affected by extreme freezing −40 °C or high cooking temperatures and will not become brittle, soft nor lose their rigidity thus enhancing consumer safety. A new type of containers has been proposed as a food vessel, termed "smooth-wall" (Fig. 1); they have flat edges, which allow heat-sealing with an organic layer and vacuum packaging. Although food packaging technology is gradually expanding toward the development of new functional products, isolated cases of failure can still be encountered.

In the case under the study, a loss of adhesion, between the polymeric lid (low-density polyethylene, LDPE) and the edges of the container (made in Al alloy 8006), was observed for smooth-wall type containers. The adhesion failure was independently observed for containers filled with hot or cold food, so the food temperature has been excluded from the possible causes of de-bonding. Further the sealing temperature (i.e. 220 °C) was carefully checked to verify its stability and its effect on LDPE melting; it was not found any malfunction in the sealing equipment. To try to find out the causes of failures, the production process of the aluminium containers was investigated.

Several samples were tested coming from different production batches. The chemical composition of the alloy used can vary in certain range according to the standard EN 573-1; as consequence, the "real" chemical composition of the alloy used, has been considered to investigate the cause of failures. In the same time it is known that iron, used as alloying element, could affect [4–6] the corrosion resistance of the material. For this reasons we have considered the "real" alloy composition (i.e. the iron percentage) to try to comprehend the cause of failures.

On the other hand it is well known that lubricant oils are necessary, during cold-forming of aluminium foils, to preserve the integrity of the tools and the work pieces, by reducing friction [7]. According to the EN 16773 [8] regulation, in the production of aluminium trays the use of vegetable or mineral food-grade oils is allowed as technological adjuvants.

The oil used in this case, is known as "Medium Chain Triglyceride"; in particular, the oil is based on triglyceride of caprylic (C8) and capric acid (C10). The acid value of this oil was maximum 2 mg KOH/g. During process 300 mg/m^2 of oil was sprayed on each side of aluminium foil

* Corresponding author.
E-mail address: monetta@unina.it (T. Monetta).

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Fig. 1. An aluminium alloy 8006 "smooth-wall" container.

resulting in an average thickness of 3 μm. It should be pointed out that the food grade lubricant oils were not removed from the surface of the containers before their use. Furthermore, for the purpose of this study, it was chosen that the material used as a lid, came from a unique production batch.

In this scenario, the focus of the current paper was to investigate the cause of the detachment at lid/metal interface and to suggest the selection of process parameters and materials to be used in the production procedure of the containers, by considering: (i) the chemical composition of the Al alloy, in terms of iron content, (ii) the effect due to the presence of the lubricating oil, (iii) the roughness of the container, considering the peaks/valleys distribution on the surface and (iv) the alloy grain size distribution.

2. Materials and methods

The containers were made of Al alloy 8006, whose chemical composition is reported in Table 1, according to the standard EN 573-1. At the end of production process, comprising the recrystallization annealing performed at 350 °C, the thickness of the aluminium sheet for smooth-wall container is in the range 0.09 and 0.15 mm. Several containers, coming from different batches, were used as samples to be tested. The first batch had an iron content of 1.63 wt%, the second 1.71 wt% and the third 1.80 wt%.

The lid was realized by a double layer polymeric film, made of LDPE and polyethylene-terephthalate (PET). The LDPE was in contact with the container edges and serves as sealing layer.

In order to assess the effect of the lubricating oil, some samples were cleaned with acetone for 15 min in an ultrasonic bath and then rinsed with distilled water, before measurements. For this reason samples used "as is" have been labelled "d" for "dirty", while samples cleaned, following the previous procedure, have been labelled "c" for "clean". In the Table 2 the nomenclature used to distinguish the tested samples in the experimental procedure along with the Fe content is reported. The amount of Fe was evaluated using an Optical Emission Spectrometer OES, ARL 3460.

2.1. Adhesion test

To maintain the integrity of the sealed package and to avoid the loss of the organoleptic properties of the food, during sterilization, normal handling, transportation and storage, a good sealing, between the vessel and the lid, must be ensured. In order to evaluate adhesion strength between the polymeric sealant film and the aluminium substrate, adhesion tests were carried out. In the adhesion test performed in this work, the "seal strength" represented the maximum load per unit width of seal, required to separate progressively the lid from the container edge. The sealing strength is relevant to set the opening force, to assure the package integrity, and to measure the packaging processes' ability to make consistent seals.

Table 1
Chemical composition (wt%) of Al alloy 8006 following EN-573-1.

	Fe	Si	Cu	Mn	Mg	Cr	Zn	Ti
AA8006	1,2–2,0	0,40	0,30	0,30–1,0	0,10	–	0,10	–

Table 2
Nomenclature used to distinguish the tested samples in the experimental procedure along with the "real" Fe content: "c" indicates "clean" and "d" indicates "dirty" (see the text).

Real Fe content (wt%)	Classification	
1.63	1c	1d
1.71	2c	2d
1.80	3c	3d

The evaluation of the seal strength was carried out following ASTM F88-05 [9], technique C, and ASTM F1921/F1921M [10], adapting the sample size to available coupons. Measurements were performed using a Kopp-Labormaster 3000 with integrated Laboratory-Sealer SGPE 3000. Force was recorded and expressed in units of N/mm. Six replicates were performed on each sample using the "dirty" type specimen.

2.2. Potentiodynamic test

Potentiodynamic polarization tests have been employed to investigate corrosion susceptibility of Al alloy 8006 in the specific environments. Tests were performed using a conventional three-electrode electrochemical cell setup (Fig. 2), in Na_2SO_4 (0.5 M) or NaCl (0.6 M) aqueous solution, aerated for 60 min by bubbling air, before the start. The cell was assembled with the aluminium sample as working electrode (WE), a saturated calomel electrode was used as reference (RE) and a platinum wire was used as counter electrode (CE). The exposed area of the specimens was 7.0 cm^2. Potentiodynamic polarization curves were recorded in a single sweep starting from −10 mV versus Open Circuit Potential (OCP) going as high as +800 mV versus OCP, or until a corrosion rate of 10^{-4}A/cm^2 was achieved.

The scan rate was of 0.20 mV/s. The OCP was recorded for a minimum of 60 min waiting, in any case, to reach a steady state. Tests have been carried out using a Solartron 1286 potentiostat/galvanostat. The measurements were conducted at room temperature (25 °C). All trials were repeated at least three times to ensure reproducibility and accuracy of the measurements.

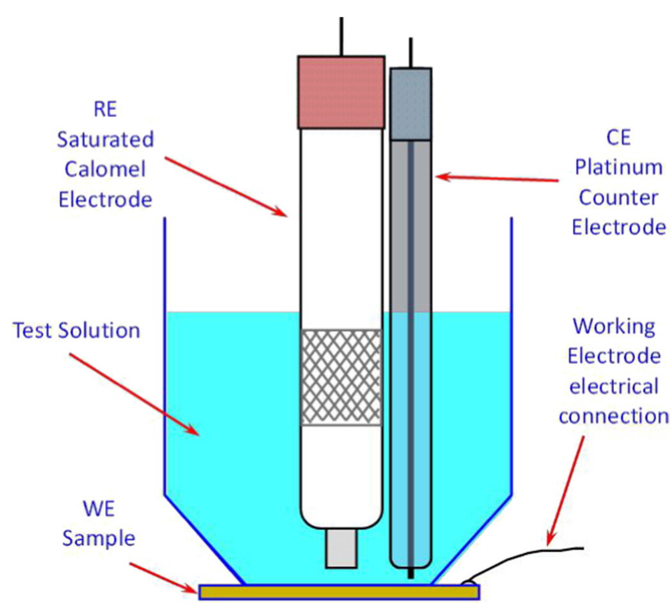

Fig. 2. A typical three electrodes cell used for electrochemical testing.