Process issues affecting the quality of Aluminium Foil: final batch anneal

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Aluminium foil remains a key material for the food and pharmaceutical packaging industries. It goes largely unnoticed in many packaged product forms, such as milk or juice cartons and the cards dispensing pharmaceutical tablets. Formability, printability and excellent barrier properties make aluminium foil the right choice for protecting and preserving the items in our ever more complex food supply chains despite the developments in barrier films from the plastics industry.

The manufacture of top quality foil for converting applications, despite its long tradition spanning more than 100 years, is often viewed as something of a black art, where many areas of the process are thought to lack scientific understanding. Under these conditions, there can be, therefore, unexplained variations due to the complex and numerous interactions of the different manufacturing steps involved from casting the aluminium to the final packaged form. Given this situation, manufacturers devote a significant amount of technical resources to maintaining processes stability so as to minimize changes that may lead to quality problems. This means that a significant portion of company know-how resides in the collective experiences of long-serving operators who can be both dogmatic and conservative. Practices that are thought to be proven are implemented, but these may be inflexible to changing conditions and in some extreme circumstances give rise to defects which are difficult to eradicate downstream or keep repeating without clear origin.

A thorough appreciation of the factors involved in the manufacturing of foil and their interactions during the different stages allows processes to be tuned to give the best results, as well as ensuring the correct response to variations in either the incoming materials or the input and output settings of the machines. Furthermore, knowledge of the expected risks involved in a process change comes only with a deep understanding of the process.

Final batch annealing of thin foil is an example of an individual process where a large number of different factors can interact to produce good or bad results. It is one of the most critical operations in foil manufacturing which has a direct impact on customer performance. For example, after annealing, a coil with an incompletely degreased surface will lead to adhesion problems during conversion process, or a coil may have poor unwinding quality which will cause tears or holes in the material when it is used in a converting process by an end user. Both instances will result in the client returning coils with the loss of reputation as well as the direct costs of lost production.

Although batch annealing is recognized as an imperfect process that leads to non homogeneous coil conditions, up to now the aluminium industry has not found a workable cost effective in-line solution that could simplify the removal of residual oil from the surface of thin foils and make the product defect proof.

A coil of the 6-micron thick converter foil is far from being solid; there is a gap between layers of less than 1 µm, which makes the effective density of the coil lower than that of aluminium.

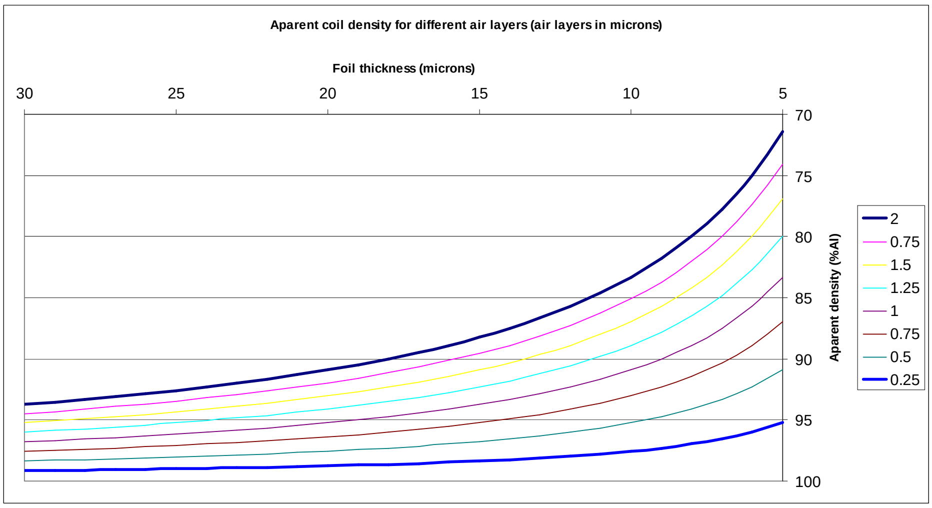

Figure 1. Relationship between coil density and gap between layers

Right after coiling this gap will be mainly filled with residual oil from the mill, while after annealing it should be mainly air. In the process of the final anneal, oil needs to vaporise and flow through the width of the coil to the edges through this small gap. This distance is commonly around 1000 mm from the centre of the coil to the edge of the coil. The physics of the oil diffusion through these gaps is a long way from normal fluid dynamics, and the pathway resembles more a porous structure than a tunnel. As the metal roughness is of the same order of magnitude as the gap, this convolutes the path the oil has to percolate through.

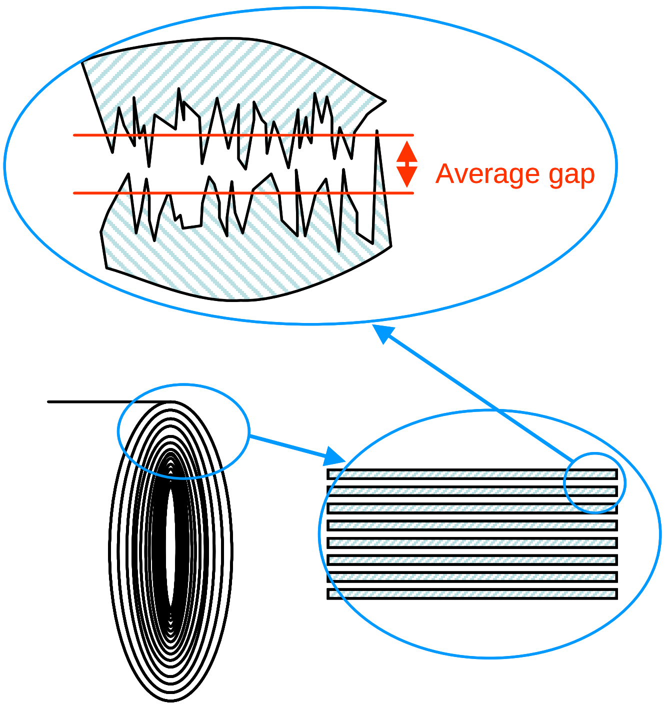

Figure 2. Schematics of gap

The Knudsen number relates the mean free path for diffusing molecules and the mean characteristic length of the diffusing geometry. For typical foil rolling oil annealing temperature and normal coiling gap geometries, Knudsen numbers will be in the range of 0.02 to 0.15. This is a clear indication that the normal continuum flow equations are no longer valid and the process is governed by rarefied flow regimes. This type of flow through long micro channels has recently received considerable attention from the microelectronics industry and several expressions have been developed that account for the governing parameters of these types of flows. As expected from industry experience there are strong influences from the air gap between laps, the coil geometry, oil characteristics, temperatures and vapour pressure. Additionally, the chemistry of the oils and the additives used during the rolling of foil products means the dynamics and energies relating adsorption to the surfaces needs to be fully considered.

An expression developed for micro channel flow of gases is

$$\dot{m} = \frac{G^3 W P_0^2}{24\mu LRT}\left(P^2 - 1 + 12\frac{2-\sigma}{\sigma}K_0\left(P-1\right)\right)$$

It is possible to estimate from it the relative influence of parameters on the process. G represents the gap and will have a key influence in the dynamics of the oil removal. L as the length of channel will determine, along with the coil heating up effects, the variation of anneal time with coil width. P accounts for the vapour oil pressure at the evaporating interface and, along with σ (a surface accommodation factor), will be affected by a change of physical characteristics due to oil chemistry.

This relatively simple expression needs to be tuned to account for non uniform gaps, blocked channels, roughness, composition of the oil, and chemical interactions that complicate the problem for each particular situation.

Factors affecting annealing performance span through the entire rolling process:

- Rolling mills will deliver coils with rolling oil on the surface of the foil that needs to be removed. Containment systems in the mills need to be set up and maintained so as to minimize the oil residuals and avoid oily patches or contaminants on the foil surface. Rolling oil chemistry and good quality control will play an important role on the process, so correct monitoring systems need to be set up. These are critical when preblended products and oil recycling are used. Adequate controls, both analytical and using the maintenance systems will ensure performance stability. A good understanding of oil contamination is needed to assess potential problems. Foil flatness will also affect subsequent coiling quality in separators.

- Separators are the final coil preparation stations which affect the strip dimensions. Correct coiling densities will ensure adequate and uniform gaps between the laps for the oil to escape, yet sufficient separation between laps to avoid stickiness due to oxide growth bridging between foil surfaces. Precise start up practices and correct maintenance of the separator actuators will ensure correct coiling quality at the core and minimize fretting corrosion defects and core stickiness issues. Good trimmed edge quality will also allow passage of oil vapour out of the coil.

- The furnaces in which the oil removal treatment occurs need to ensure uniform temperature distribution, precise atmosphere control and purging. Therefore, correct maintenance of furnaces is important. Variable coil geometries (both in coil sizes and material thicknesses) need to be addressed by different annealing practices. Measures can be put in place to minimise overheating of the support cores which significantly influences unwinding performance close to the core.

If, in spite of these measures, problems arise, forensic surface chemistry techniques (Surface carbon, GC, TGA, FTIR, etc.) and experienced trouble-shooters are invaluable in quickly detecting and identifying the origins of the problems. The correct mix of plant data analysis, field measurements and laboratory analytical measurements combine to pinpoint weak points in the process and identify the likely origin of defects.

A key approach to asses the suitability of a surface for coating involves the use of both FTIR and surface carbon measurement, both of which are offered by Innoval Technology, a leading provider of independent technical expertise to the global aluminium industry.

FTIR is used to measure the chemical nature of the aluminium surface and it can detect the presence of hydrocarbon products on the surface or the state of hydration of the outermost oxide layer. The nature of the oxide layer has a strong impact on the performance of coating adhesion. A technique has been developed that allows precise quantification of the thickness of the oxide layer in the foil. Changes in oxide thickness and chemistry will alter the adhesion response of the foil.

Surface carbon measurement is another useful technique that gives quantitative values to the amount of residual carbon products on the surface remaining after anneal. The traditional wettability measurement approach only gives semi quantitative information about the surface tension with water, whereas measurement of the total amount of carbonaceous residues present can be quantitatively linked to adhesion performance.

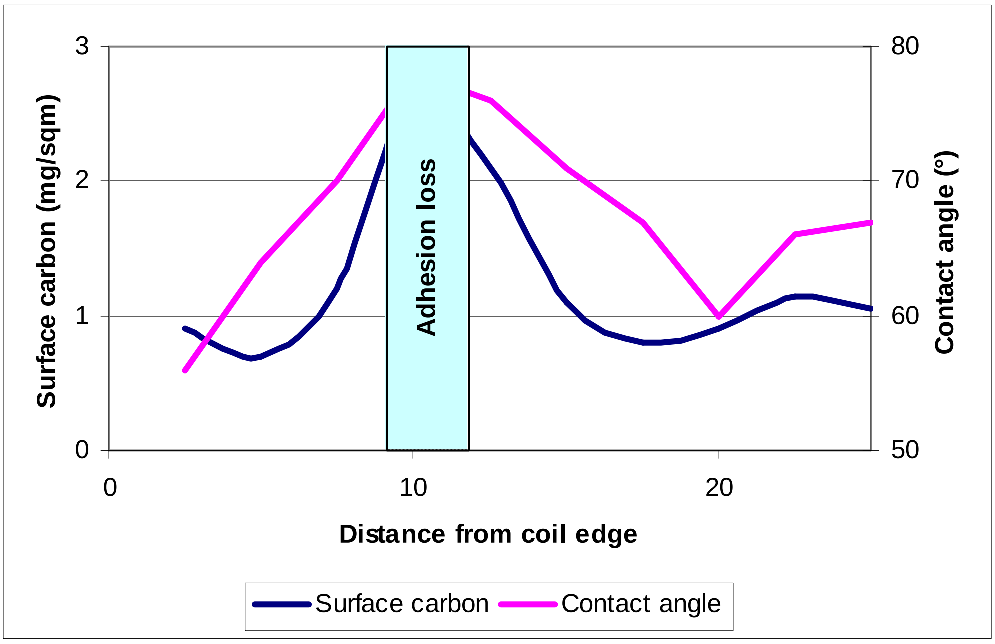

Figure 3. Relationship between carbon content on the surface and adhesion performance

Furthermore, the use of thermal programmes during the test can highlight the presence of heavy ends from the lubricant or polymerized species. In figure 4, material A shows a higher amount of higher weight products that evolve at higher temperatures. It is expected that anneal of this material is comparatively more difficult and adhesion performance will be poorer.

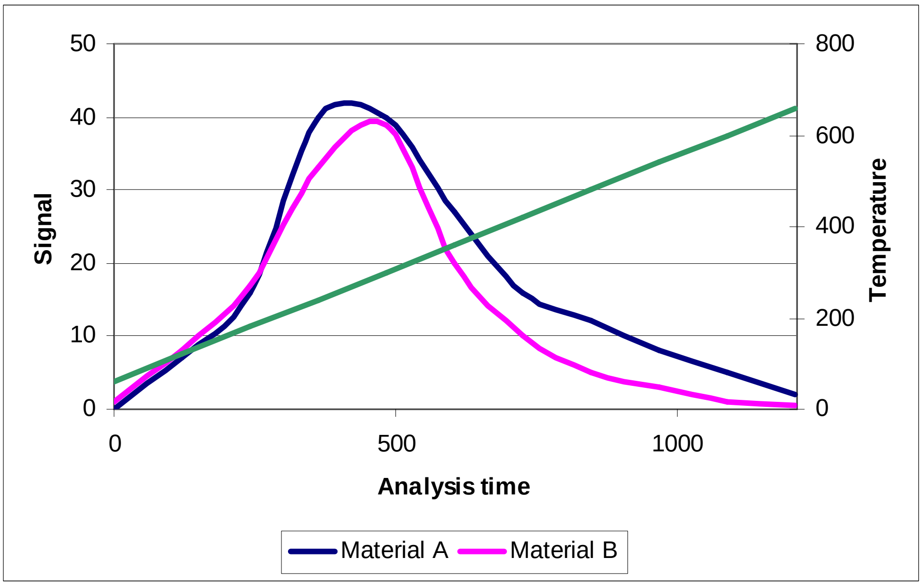

Figure 4. Behaviour of surfaces with different species

With sound analytical capabilities and field technical expertise, and strong thermal modelling capabilities, the team at Innoval Technology can play a key role in optimising annealing processes. They can also assist with troubleshooting product performance in foil manufacturing, setting reliable process controls and staff training.