Paying Attention to Layers in-between

Continuous Compression Molding Multilayer of Coffee Capsules

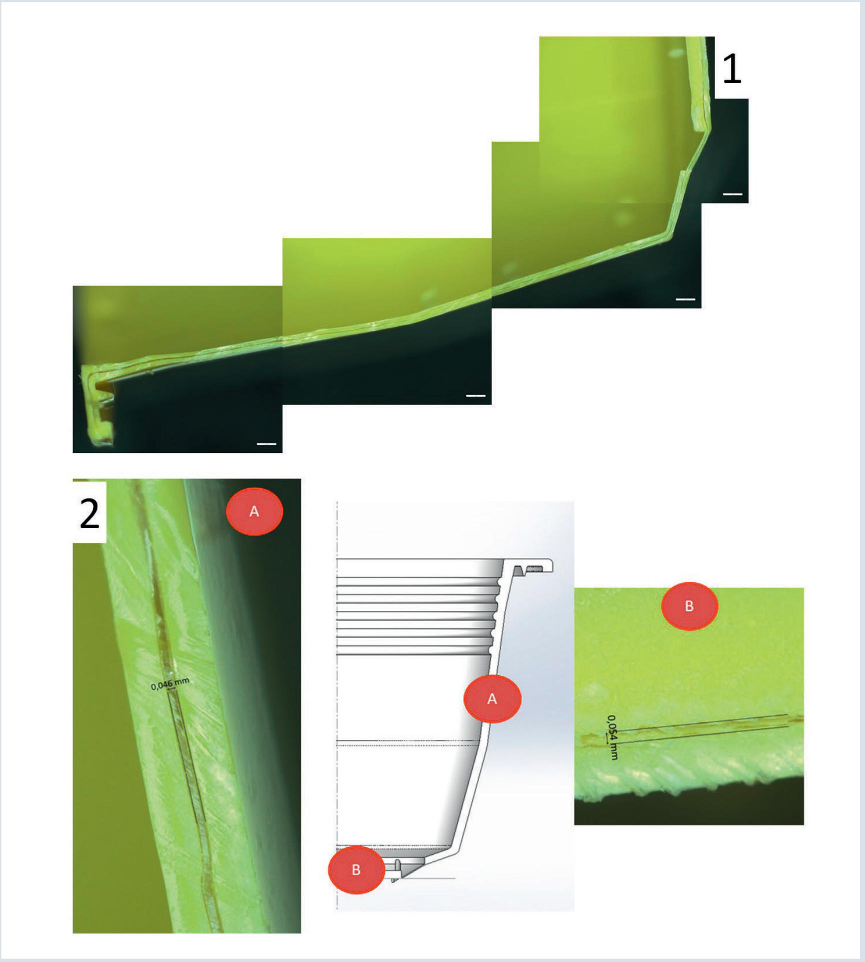
Continuous Compression Molding (CCM) technology can be applied to multilayer solutions and is referred to as Continuous Compression Molding Multilayer (CCMM). In addition to the usual benefits of CCM it offers further advantages over competing technologies. In packaging applications, compression technology makes it possible to use minimal quantities of barrier material, thus combining excellent performance with low raw material costs.

The Continuous Compression Molding Multilayer (CCMM) process lets manufacturers obtain plastic objects consisting of several bound-together layers of material. It is divided into three main stages:

- Formation of multi-layer polymeric melt,
- dose cutting and insertion,
- mold compression, forming and extraction.

During the first stage the various materials are melted and fed into the co-extrusion head. Here they merge, forming a single multi-layer melt. The material making up the central layer (marked dark blue in **Fig. 1**) is fed into the center of the co-extrusion block; the two adjacent layers (red section in **Fig. 1**) are inserted laterally, "sandwiching" the former. Lastly, the outer materials are added – again, laterally – in successive stages in order to ensure good adhesion. Note that in **Figure 1** the outer materials are represented with two different colors (orange and green) for illustrative purposes. Depending on the required configuration, the outer materials may, in fact, be the same or different.

To adjust and optimize distribution of the various polymeric layers, the co-extrusion head incorporates several levers that can be used to obtain the desired distribution. This aspect is fundamental because layer distribution in the finished product greatly depends on layer distribution within the multilayer melt. As **Figure 2** shows, the ethylene vinyl alcohol copolymer (EVOH) layer is protected on all four sides to prevent any spillage of the material. EVOH layer width and homogeneity can be modified by acting on mechanical parameters in the co-extrusion head (i.e. the above-mentioned levers). Again, the aim is to control distribution of the multilayer melt to ensure correct layer distribution in the molded object.



EVOH distribution in a compression-molded multilayer capsule produced by CCMM: 1) complete distribution over cross-sectioned capsule, 2) enlargement of two zones (bottom and wall) of the capsule © Sacmi

The multilayer melt exits the extrusion nozzle at a constant flow rate; that rate is regulated by volumetric »

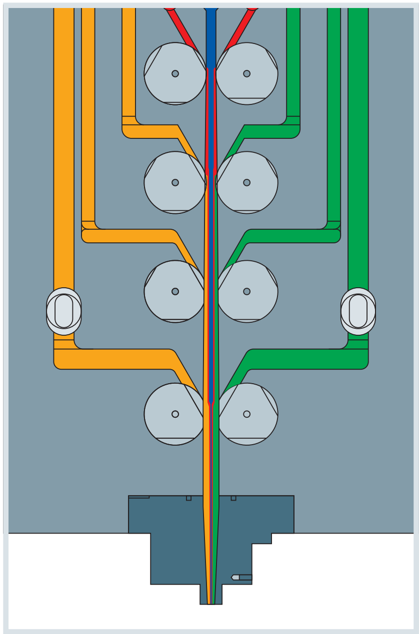


Fig. 1. Cross-section of multilayer melt co-extrusion forming head Source: Sacmi; graphic: © Hanser

pumps downstream from each individual extruder. The material is then extruded into air (**Fig. 3**). Subsequently, a small portion of melt exiting the nozzle (and weighing the same as the final product) is cut by a conveyor system; the latter, in fact, has the purpose of cutting and transporting this small portion of multilayer melt into the mold (**Fig. 4**). Just before it reaches the mold, the conveyor system rotates 90° (**Fig. 5**). The mold, which consists of a male and a female part, is, at this stage of the process, open and ready to receive the dose to be molded.

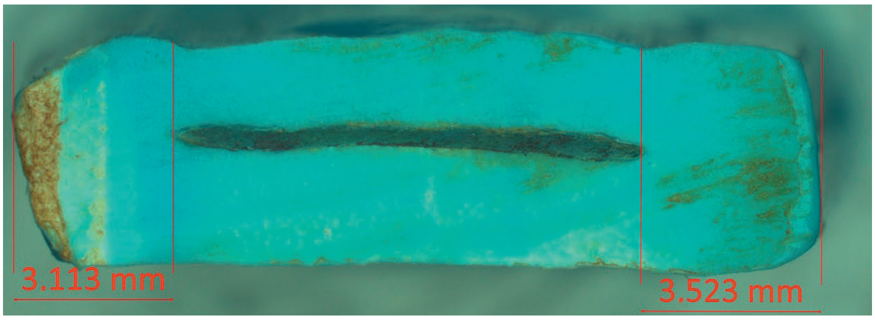


Fig. 2. Cross-section of a portion of multilayer melt exiting the extrusion nozzle. The light blue area is the colored polypropylene (PP) while the black line is the EVOH (oxidized with iodine to make it clearly visible). Being transparent, the compatibilizer is somewhat hard to distinguish © Sacmi

The dose is then placed over the male section of the mold, leaving the conveyor system empty and ready to cut a new dose. Lastly, the dose is compression-formed as the male section is raised into the cavity, closing the mold. During carousel rotation, the object cools down completely. At the end of the cycle the mold opens, and the finished product is extracted before being aligned over a conveyor belt as shown in **Figure 6**.

Role of Compatibilizers

At present, CCMM technology is mostly used to produce multilayer coffee capsules; however, it could be applied in other sectors, such as the manufacture of cups, trays and preforms for bottles and other PET containers, etc. The number of layers making up the final object varies from three to nine according to product requirements. For example, in the case of coffee capsules, the layer sequence is as follows: polypropylene (PP) – compatibilizer – ethylene vinyl alcohol (EVOH) – compatibilizer – polypropylene.

In the specific case of coffee capsules, EVOH is defined as a barrier material as it introduces oxygen barrier properties into the final packaging. PP, on the other hand, has a structural function. Its properties – and how they combine with product design – determine the mechanical performance of the object. In this configuration, a compatibilizer is needed because EVOH and PP are incompatible.

But not all barrier materials need a compatibilizer to adhere to the corresponding external structural polymer, as is the case with nylon (barrier material) and polyethylene terephthalate (PET). Using these two materials it is possible to obtain a compatibilizer-free packaging product made up of just three layers, in which the nylon is sandwiched between the PET layers. However, the degree of adhesion achieved without using a compatibilizer may not always be sufficient for the required application; so – even with nylon and PET – it may still be necessary to insert compatibilizers between the two materials to obtain a 5-layer configuration (which is easily managed with a CCMM process). This cannot be implemented in all molding techniques. With co-injection, for example, manufacturers are restricted to a maximum of three layers.

Barrier materials and compatibilizers are usually special polymers, specifically designed to equip the packaging with

Ethylene content	**MFR (melt flow rate)**	**OTR (oxygen transmission rate)**
[% mol]	[g/10 min]	[$cm^3/m^2 \cdot d$]
29	4	0.2
27	4	0.1
27	8	0.1
27	2	0.2
32	1.6*	0.3
35	17	0.5
35	22	0.3
38	1.7*	0.7
44	5.5*	1.9
48	6.4*	3.7

MFR measured at 210 °C (at 190 °C) and 2.16 kg*
OTR measured at 20 °C and 65 % relative humidity

Table 1. Melt mass flow rate (MFR) and oxygen transport rate (OTR) of selected commercial EVOH as a function of ethylene content, measured on a 20 µm thick film Source: Sacmi

certain properties; however, they are also much more expensive than thermoplastic commodities such as PP and PET. It is therefore essential to optimize their quantity in the finished product, since this will ensure that the final product is both high-performance and economic.

Fig. 3. Multilayer melt (bottom right) exiting the extrusion nozzle © Sacmi

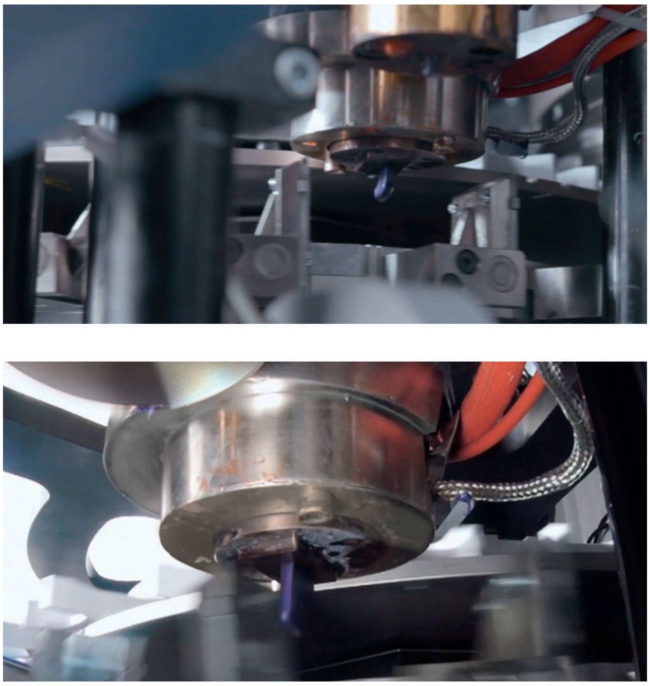


Fig. 4. The cutting and conveying of the desired melt doses is an essential stage of the entire process © Sacmi

Use of EVOH

EVOH is a copolymer consisting of ethylene and vinyl alcohol. Its barrier properties depend on how much vinyl alcohol (% mol) is in the polymer. The higher the quantity of vinyl alcohol, the better the barrier properties. The market offers various grades of EVOH which differ in ethylene content; the lower that content (% mol), the better the barrier properties. Ethylene content also affects the viscosity of the molten polymer. This last aspect is crucial because it can be a limiting factor for a specific forming technology; a compromise therefore needs to be found between viscosity, barrier effect and the thickness the polymer must have in the final product to obtain the desired insulation.

As can be seen in **Table 1** showing oxygen transmission rates (OTR) for commonly available EVOH grades as a function of ethylene content, the grades with the best barrier properties ($< 0.2\,\text{cm}^3/(\text{m}^2 \cdot \text{d})$) are those with the lower melt flow rates (MFR). There are grades with low MFR and OTR $> 0.3\,\text{cm}^3/(\text{m}^2 \cdot \text{d})$, but no grades with high MFR and OTR $< 0.3\,\text{cm}^3/(\text{m}^2 \cdot \text{d})$. Consequently, if a molding technique is unable to process low-MFR materials, it must necessarily process EVOH with barrier properties worse than those provided by low-MFR grades and it will therefore be necessary to increase the EVOH content to obtain the desired shelf-life.

Note that cost of the materials shown in the table increases as ethylene content decreases. However, cost does not increase linearly with improvements in barrier properties, and, as to be learnt from the relation between OTR and cost ratio, it is always preferable to use more expensively low ethylene content grades with barrier properties that make it possible to minimize the quantity of barrier material inside the packaging.

Processing Technologies

Packaging barrier properties, in turn, depend on both the nature of the used material and its distribution. Consequently, the choice of material and the way it is processed are essential. In fact, the techniques which, apart from compression, can be used to make multilayer products are co-injection [1] and thermoforming [2–4]. The main »

Technology	Barrier material	Barrier material thickness	Barrier material distribution	Voids or holes	EVOH content [% m/m]
Compression	Resin with low ethylene content	Thin layer of EVOH	Complete inside the molded product	Improbable but CVS can detect them	3–4 %
Co-injection	Resin with high ethylene content (high MFR)	Difficult to obtain thin layers of EVOH	Complete but difficult to obtain	Present in flange and near gate	6–8 %
Thermoforming	Resin with low ethylene content	Uneven thickness	Defects may be present	Probable due to stretching	5–7 %

Table 2. Main characteristics of the barrier layer obtained in packaging molded by compression, co-injection and thermoforming Source: Sacmi

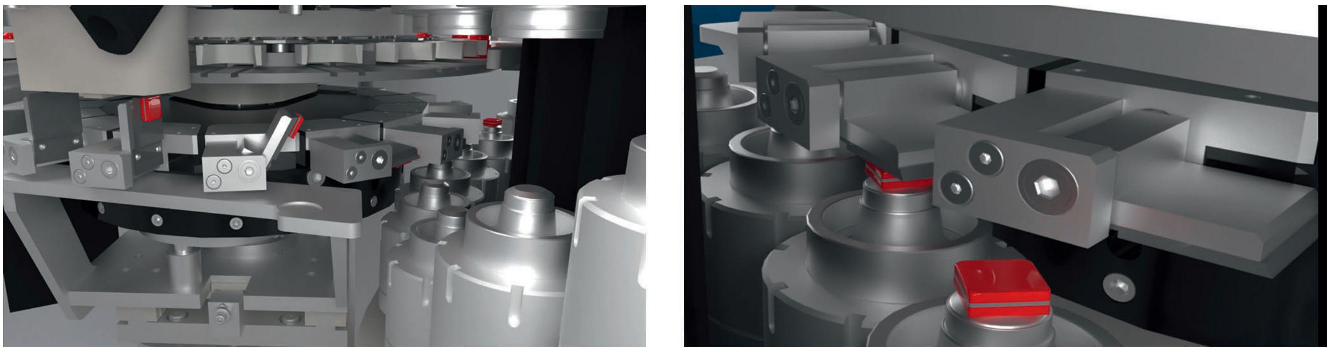


Fig. 5. Close-up of the multilayer dose cutting and conveying system mechanism that rotates 90° just before it reaches the mold © Sacmi

characteristics of these molding techniques are shown in **Table 2**.

Compression technology allows excellent flexibility in terms of the variety of usable resins; it is, in fact, possible to use barrier materials of low ethylene content that are more viscous and efficient in terms of gas impermeability. Lower amounts of EVOH can therefore be used in the final product (barrier properties remaining equal) compared to items molded using EVOH with worse barrier properties. This means that the used materials have a lower unit cost. Another key feature of the compression molding process is that it results in a complete, void-free EVOH layer that runs the entire height of the packaging. This aspect ensures excellent barrier properties.

Fluid-dynamic simulation has shortened the development times for this technology and confirmed that the CCMM process makes it possible to consistently obtain capsules with uninterrupted EVOH distribution. **Figure 7** shows how the different layers of material are distributed completely and homogeneously during mold closure.

The **Title figure** and **Figure 8** compare actual distribution in capsules made by means of three different technologies. All images refer to samples found through standard retail distribution channels. As the **Title Figure** shows, for, the compression-molded capsule, the inner EVOH layer is complete and homogeneous from the bottom of the object to its top. The cross-section images in **Figure 8** show how, in some cases, co-injection can result in sub-optimal adhesion of the three layers, with consequent separation of individual capsule layers.

Furthermore, with co-injection it is difficult to obtain a complete EVOH layer. In fact, it is not unusual to find – especially near the injection gate (indicated by the arrow) and in other zones – points of lacking EVOH. These barrier material voids have a huge effect on the final OTR because they are oxygen-permeable, oxidizing the packaging contents.

Compression technology enables to deposit the compatibilizer as a homogeneous layer only at the interface between the two materials that actually need to be made compatible. Other molding techniques unable to handle more than three layers of material require mixing of the compatibilizer with the external polymer layer. Consequently, in the latter case it is necessary to use much more compatibilizer to obtain the intended result. **Table 3** shows the quantities of compatibilizer typically used in some molding techniques. As observed for the barrier material, compression technology also allows for the

Table 3. Comparison between quantities of compatibilizer typically used in different molding techniques Source: Sacmi

Technology	Adhesive layer	Adhesive content
Compression	Separate layers	2–4 %
Co-injection	Mixed in the main material	10–15 %
Thermoforming	Separate layers	3–5 %

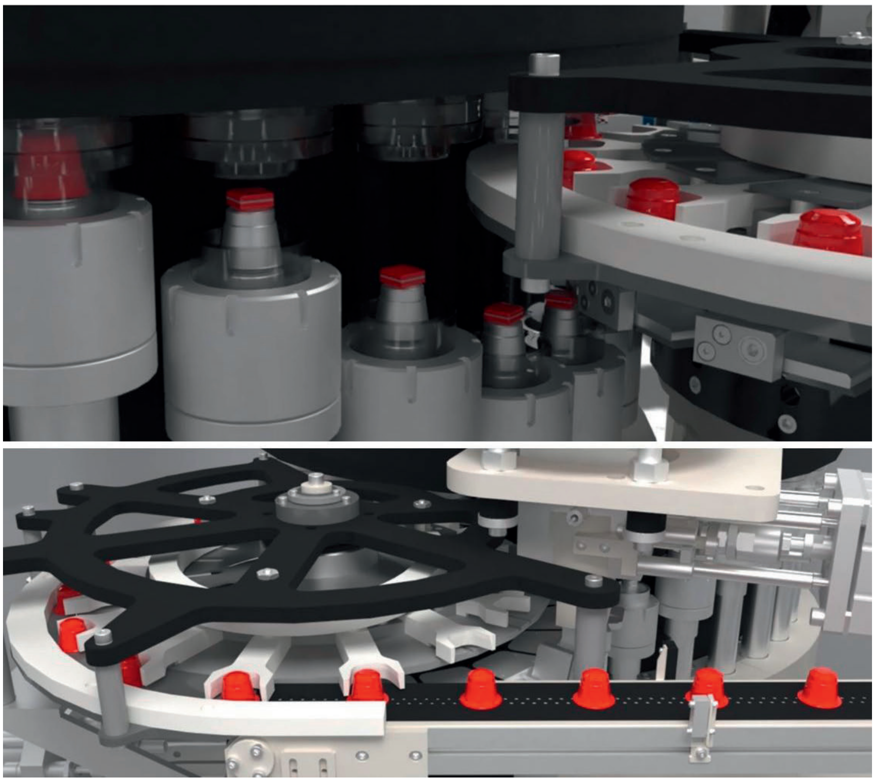


Fig. 6. The capsule is extracted from the mold © Sacmi

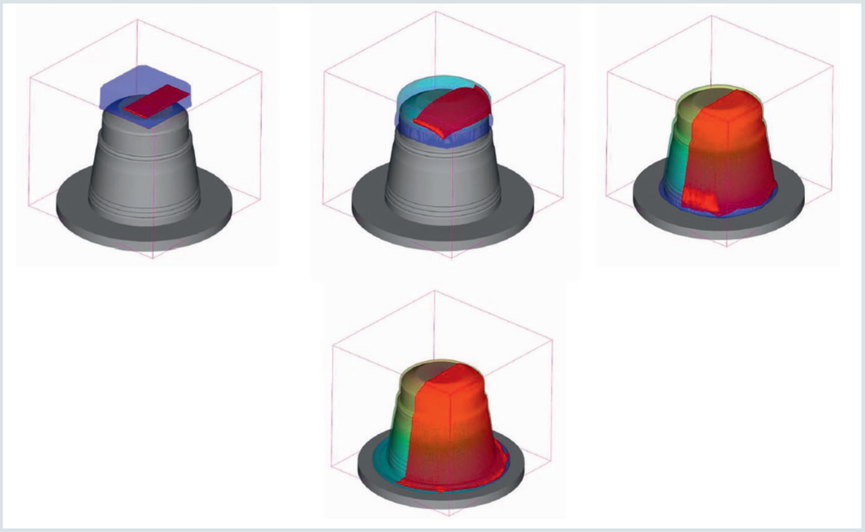


Fig. 7. Computer simulation showing the distribution of five layers of material during coffee capsule compression molding. For purposes of clarity, only half of the actual EVOH layer is shown (in red) © Sacmi

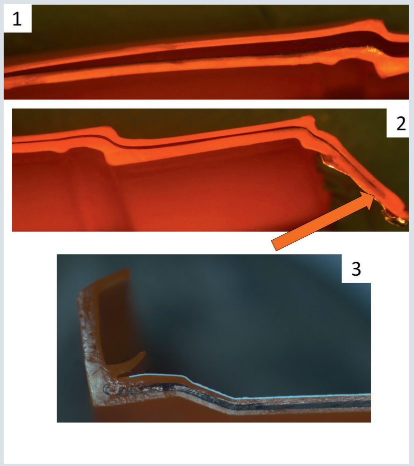


Fig. 8. Distribution of EVOH in a multilayer capsule molded by co-injection: 1) possible effect of layer delamination, 2) and 3) possible voids or incompleteness of EVOH layer © Sacmi

	EVOH [% m/m]	Compatibilizer [% m/m]	Colorant [% m/m]	External layers [% m/m]	Cost of raw materials per 1 million capsules [EUR]
Case 1	4	2	1.8	92.2	4364
Case 2	6	4	1.8	88.2	4749
Case 3	7	5	1.8	86.2	4936
Case 4	7	12	1.8	79.2	5453

Table 4. Cost of 1 million capsules according to the packaging composition Source: Sacmi

use of smaller compatibilizer quantities than other forming methods. A compression-molded capsule that typically has OTR values of less than 0.0005 cc/pkg·day·air (capsule surface approximately 2500 mm^2; pkg for single package) consists of 4 % EVOH and 2 % compatibilizer.

Since the material accounts for 50 to 60 % of total capsule cost, cost analysis shows how advantageous it is to optimize use of the most expensive materials in multilayer packaging (**Table 4**). Internal tests confirm that the economic advantages of compression technology do not entail any compromise in terms of product quality. Indeed, it has been demonstrated that capsules with excellent barrier properties and layer adhesion can be molded.

Quality Control

As another key CCMM feature, capsules are pre-oriented when they exit the molding process (**Fig. 9**). Consequently, they can be checked on the line without any need for a positioning device between molding machine and vision system. With the Sacmi CCMM solution all capsules are checked by two vision systems. The first vision system measures capsule ovality and checks for unwanted black specks, bubbles, color variations, etc. Capsules that do not meet specifications are automatically discarded. The second vision system analyses the internal barrier layer, checks whether it is present along the full height of the capsule and discards any items with barrier layer defects. Additionally, from the intensity of the colors in the image captured by the barrier layer vision system it is possible to deduce the in-capsule EVOH content. The vision systems (**Fig. 9**) are highly useful for the immediate identification of any machine „drift“ caused by errors such as insufficient material being fed to an extruder or moisture in the EVOH layer.

Tables 5 and **6** show OTR values as measured on capsules of different sizes as a function of the barrier layer quantity. All values refer to CCMM-made capsules. The data in **Table 6** show that using high performance barrier materials and distributing them correctly within the capsule allows molding of capsules with excellent OTR values that ensure long shelf life of the packaged products. »

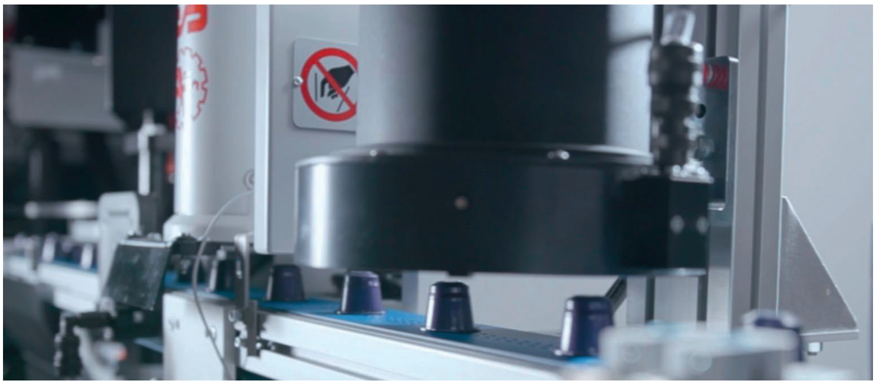


Fig. 9. Continuous analysis of all manufactured capsules with two different control systems © Sacmi

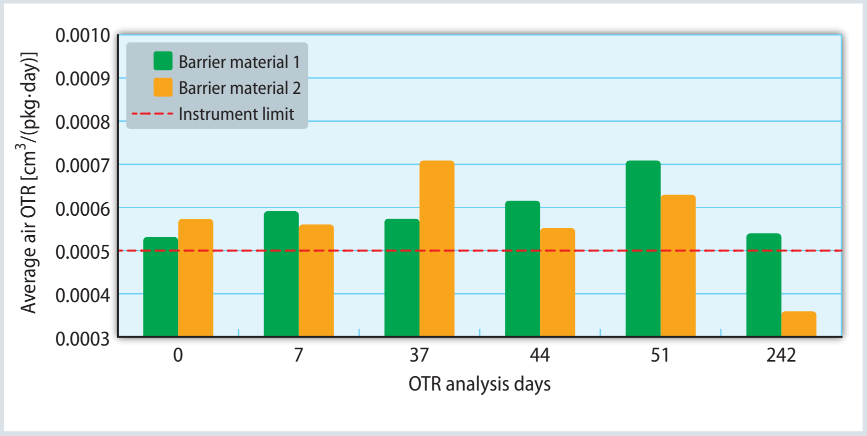


Fig. 10. Oxygen transmission rates in capsules molded with two different grades of barrier material over time Source: Sacmi; graphic: © Hanser

Being a hydrophilic polymer, EVOH tends to absorb water when exposed to air. As absorbed moisture content increases, barrier properties worsen. OTR analysis was therefore conducted on the same batch of capsules at regular time intervals. This was to verify that the capsules do not irreversibly absorb water (which would, as stated, worsen the oxygen permeability of the molded object). The data was acquired by molding two samples of 5-layer capsules (PP – compatibilizer – EVOH – compatibilizer – PP). The two samples differed in terms of the grade of EVOH used, not its quantity. It was decided to use a percentage of EVOH that made it possible to have an OTR higher than the sensitivity of the instrument, thus allowing assessment and quantification of OTR changes over time. **Figure 10** shows how OTR remains virtually unchanged over time. Observed fluctuations, in fact, are attributable to normal variations caused by the measurements inevitably being made under different conditions. It is important to point out that no worsening of results over time was observed; even when the OTR is seen to increase, it drops back again a few weeks later.

It should also be specified that OTR analysis is conducted after letting the capsules „settle" in the external environment, of controlled temperature and humidity (the result is therefore influenced by this unavoidable process). OTR data over time, however, demonstrates that the capsules do not absorb moisture irreversibly and that their characteristics remain unchanged over time.

Lastly, as with the CCM process, the CCMM sequence does not produce any scrap, an advantage of particular importance when processing multilayer materials. This is because reprocessing multi-material scrap causes several problems during extrusion (compatibility problems, formation of EVOH gels, etc.) which complicate the technological process and limit the amount of scrap that can be re-used in the production process. ■

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References & Digital Version

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German Version

- Read the German version of the article in our magazine *Kunststoffe* or at *www.kunststoffe.de*

EVOH	OTR_{Air}	OTR_{Air}	$\text{OTR}_{\text{Oxigen}}$	$\text{OTR}_{\text{Oxigen}}$
[% m/m]	[cm^3/pkg·d]	[cm^3/m^2·d]	[cm^3/pkg·d]	[cm^3/m^2·d]
0	0.1150	46.36	0.5473	220.7
2.3	< 0.0005*	< 0.2016*	< 0.0024*	< 0.9600*
3.8	< 0.0005	< 0.2016	< 0.0024	< 0.9600
6.5	< 0.0005	< 0.2016	< 0.0024	< 0.9600

** The process requires specific adjustments and optimal EVOH distribution is not always attainable.*

Table 5. Oxygen transmission rates measured on CCMM-made capsules with a surface area of 2480 mm^2 (measured at 25 °C and 35 % relative humidity, pkg for single package) Source: Sacmi

EVOH	OTR_{Air}	OTR_{Air}	$\text{OTR}_{\text{Oxigen}}$	$\text{OTR}_{\text{Oxigen}}$
[% m/m]	[cm^3/pkg·d]	[cm^3/m^2·d]	[cm^3/pkg·d]	[cm^3/m^2·d]
2	0.0032	1.0207	0.0152	4.86
4	0.0011	0.3509	0.0052	1.67
6	0.00059	0.1871	0.0028	0.89

Table 6. Oxygen transmission rates measured on CCMM-made capsules with a surface area of 3135 mm^2 (measured at 21 °C and 40 % relative humidity, pkg for single package) Source: Sacmi