MODEL FOR INTER-DIFFUSION OF POLYMERS ON SEALING

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Laundry detergents pods are water-soluble pouches containing highly concentrated laundry detergent, perfume, softener and other laundry products like a brightener. They first became popular in February 2012 when they were introduced by Procter & Gamble as Tide Pods; now there are several different brands on the market (Dash, Ariel, Fairy, etc.) with different colours, shapes and features leading about 15% of the $7 billion-a-year U.S. laundry detergent market sale.

A pod is basically made by two films of Poly-vinyl alcohol, modified to become highly solvable in hot water, sealed together with a pre-dosed quantity of detergent inside, aiming to avoid wastes in comparison to liquid formulations.

Sealing of PVOH films is a challenging transformation, involving several phenomena strongly linked to each other. Many Product Quality parameters are linked to Sealing, from the legally required Pouch Strength to Process Reliability where 1% PR loss due to Unplanned Down Time accounts to approximately 35000$ per line per year base on Manufacturing-Operating Expenses alone. Moreover, poor sealing can of course cause leaks, one of the biggest consumer complaints. One should take into account that leakage in one pod can also affect the others contained in the same package, making them sticky or creating holes in the polymeric film. This means that a single poorly sealed pouch can ruin an entire pack.

The tests that are now performed to calculate seal strength are not only disruptive (e.g., rupture test of the pods with hydraulic press) but also, they do not give any insight about the deficiency in the process that led to a bad sealing quality.

Thus, it is understood that a deep knowledge of the phenomenon in every aspect is needed, in order to better catch the impact of any parameter on the welding strength. The objective of this Ph.D. thesis is to investigate the fundamentals of solvent sealing on a physical basis, being capable to build a predictive model for the welding strength.

Such a kind of model has to take into account every phase of solvent sealing process, namely:
- Solvent diffusion along the first polymeric film;
- Diffusion of solvent in the opposite verse, towards the dry film;
- Polymer motions between films, creating the joint.

Moreover, the role of thermodynamic conditions, like Temperature and Relative Humidity, in seal aging has to be considered: the welding of the two films must in fact be maintained until the consumer uses the pods and thus changes in external environment should not affect the interpenetration of polymer chains.

In the industrial process we are considering, water is the catalyst to polymer diffusion which ultimately leads to the bond of PVOH films by entanglement. The first step we have to consider is thus the diffusive behaviour of low-molecular-weight molecules in polymer matrices, that is generally observed to be non-Fickian.
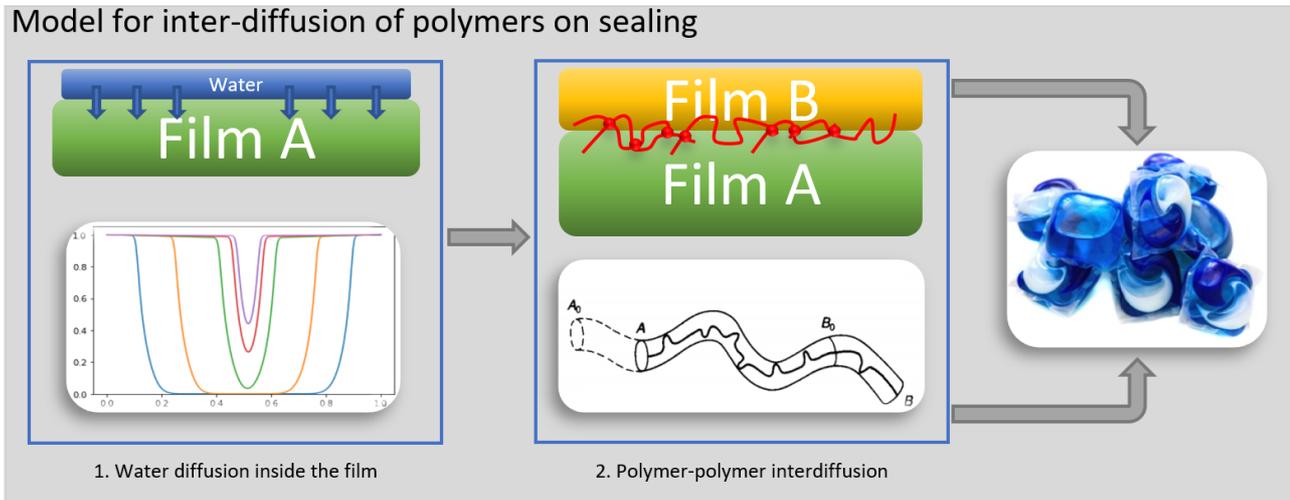
In order to investigate the nature of solvent diffusion, penetration distance (by optical microscopy) and mass absorbed by the film (gravimetrically) are measured as functions of time: both of them are well described by a power-law fit, with an exponent higher than 0.5. This indicates the anomalous features of water transport and highlights the need to abandon the standard Fickian diffusion to embrace more complex models, capable to take into account systems the increase of the film volume due to the penetration of water (swelling).

With regard to the formation of the junction, a large number of models also exist, but the ones based on polymer-polymer interdiffusion seem to give the best quantitative results. Usually, such models refer to polymer reptation dynamics as introduced by deGennes, where it is expected that, on increasing the time of contact between the two films, new topological constraints will be created across the interface, thus improving the seal strength.

Once the optimal models for the intermediate steps (solvent diffusion and polymer interpenetration) are found and validated on the basis of experimental proofs on PVOH films, a direct link between water concentration and polymer entanglements needs to be found, in order to explain the dependence of peel strength on the time given to the water to diffuse inside the first film. The final aim is thus to quantitatively link the two phenomena together, building a model for the entire solvent sealing process; this model should be then translated in an easy-to-use tool to predict the seal strength using as basis material properties of the film and thermodynamic conditions.

A predictive model based on first principles like this has several advantages. First of all, it takes into account a given number of parameters and independent variables, which will be identified by the researchers as significant predictors of a high-

quality sealing. This means that the parameters estimate may be done through selected and controlled experiments. Also, a predictive model can be used to forecast what is the best combination of factors, among those analysed, which can actually lead to the outcome desired, i.e., the best welding process possible in a cost-efficient way.

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1. Water diffusion inside the film   2. Polymer-polymer interdiffusion

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