Data Science and Artificial Intelligence for smart sustainable plastic packaging

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Background & Aims

The project has started by looking at flexible packaging. Flexible packaging is made by building up layers of polyolefin films which are created by extrusion blow moulding. At the bottom a polyethylene (PE) layer is in contact with the product. There are two more PE layers above, followed by an adhesive layer and a print layer (see image below).

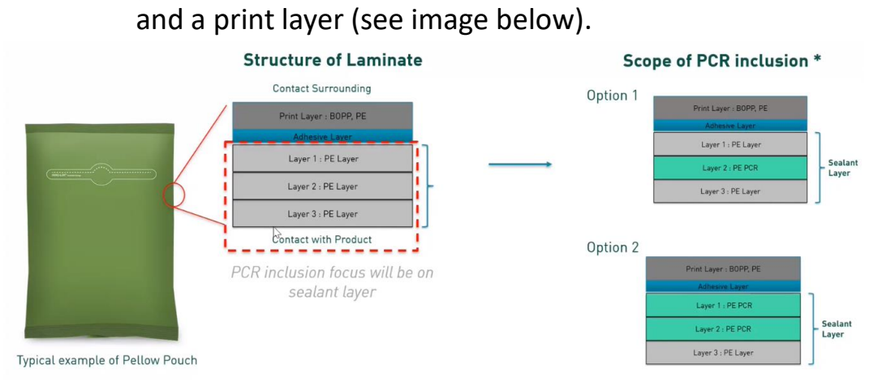


Fig 1: An example of a typical flexible pouch made by industrial partner Unilever.

Incorporation of 100% recycled plastic (PCR) is a challenge, because it can't be in contact with the product for safety reasons. We are therefore restricted to a maximum PCR content of ~80% (print layer + middle layers). At present most flexibles are ~30% PCR, so there is large room for improvement.

So why can't we go 80% PCR straight away? It is the case that PCR products contain contaminants from waste streams, become degraded by oxidation due to thermal processing and have a wide range of molecular weights present.

These factors can significantly lower the performance of the film for a given application and are normally indicated by the presence of gel spots.

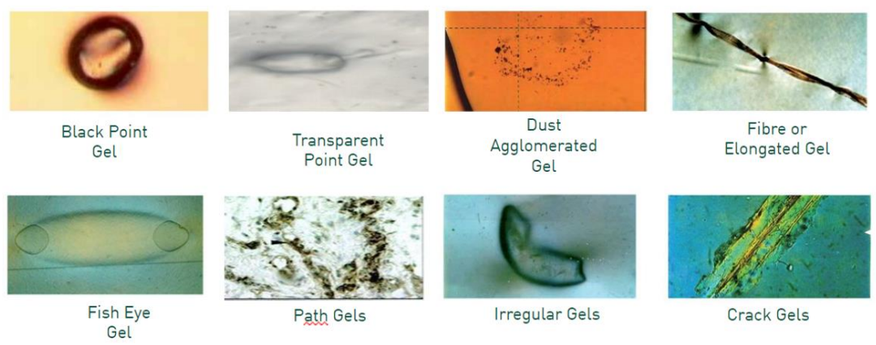


Fig 2: Examples of some of the typical types of gel spots seen in PE films made from recycled plastics [1].

Many of these gel spots relate to specific contaminants. For example, fibre gels commonly indicate the presence of polypropylene (PP) or nylon contaminants. When stretched, the film is more likely to tear at these specific points.

Overarching aims of the project:

- Characterise the type, size, shape and spatial distribution of gel spots for a range of different PE films with different PCR content/PCR feedstocks.
- Predictively link this information about gel distributions to relevant performance properties of the films (sealability, likelihood to tear etc).
- Go back to the original PCR pellets to see whether the distribution of gel spots could be predicted from indirect structural information (e.g FTIR/DSC/XRD).

Research Plan

Phase 1

- **Get initial films:** Gather a small batch of films with a varying PCR content for initial imaging.
- **Determine the best quality imaging technique:** Transmission scanner/HD camera/microscopy techniques
- **Research and apply gel spot recognition techniques:** The perfect outcome would be a number of accurately classified films. This first stage will mainly be a proof of concept rather than the actual experiment.

Phase 2

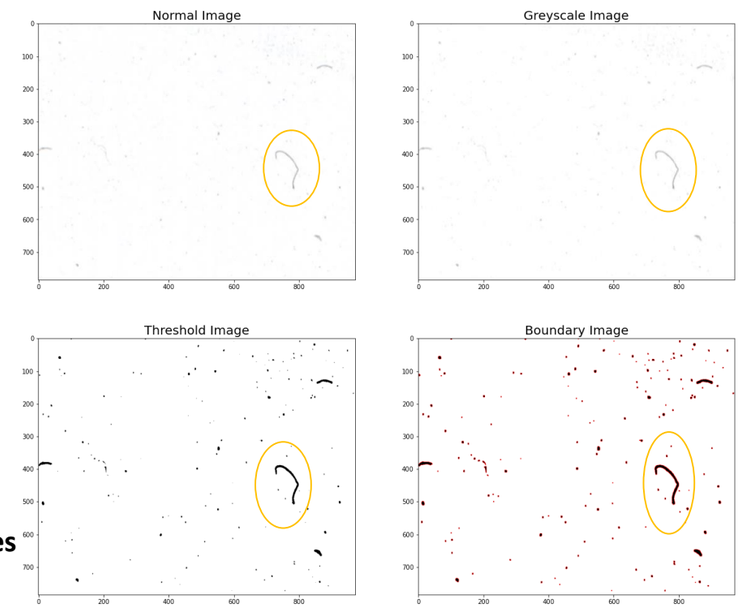
- **Get finalised list of films and gather image data:** Here we chose a variety of films to represent a range of PCR contents/feedstocks which will allow us to answer our research hypotheses.
- **Apply the best gel spot recognition technique (from Phase 1)**
- **Make corresponding laminates and measure performance properties**
- **Predictively link the measured gel spot distributions to performance properties**

Phase 3

- **Predictively link measured spectra from the PCR pellets (FTIR/DSC/XRD) to gel spot concentration:** This allows us to see whether a given PCR will make an acceptable film without having to physically make it, and will allow us to design a manufacturer specification.

Computer Imaging

We can get relatively high quality images of the film using a simple transmission scanner. An example image is shown below (top left – raw image, top right – greyscale version, bottom left – binary image from simple thresholding, bottom right – binary image with boundaries drawn).



We see plenty of small gel spots, but also a few larger thin/long particles which can almost certainly be attributed to dust on the surface of the film. We can either remove these dust particles via physical cleaning or we can use some image morphology analysis to remove them.

The disadvantage of image morphology analysis is that occasionally the particles are embedded (see example below where the same particle is present before/after cleaning).

However, a useful feature of embedded particles is that they produce a refractive effect where a spectrum of light encircles the particle. Work is currently being done to incorporate this effect into an image filtering method.

Future Work

- **Take some more image scans:** At the moment the library of film scans is limited. Collecting more data will allow more accurate classifications to be made of the gel spot distribution
- **Work on specific spot type identification:** Given that the imaging allows us to classify the shape and distribution of the gels, by using a chemical technique like Raman microscopy, we can label the types of gel spot present and then build an ML model which classifies the gel spot types in the film.
- **Test the mechanical properties of the films:** Do the films seal together easily, or do they break apart? Do the films have desirable tensile properties? Can these properties be linked to the distribution of gel spots?

Conclusion

This project will explore whether we can predict the performance properties of recycled plastic films by imaging them and quantifying the gel spot distribution. We will then attempt to link this gel spot distribution to both the performance properties of the film, and the structural properties of the original plastic pellet.

A good outcome would be to have the ability to decide whether a sample will be appropriate in advance of making the final product, thus saving time/money. This will also reduce plastic waste in the environment, because choosing the ideal recycled pellets will allow us to maximise PCR inclusion in the product.

References

[1] 'Gels in polyethylene films' information sheet - *ExxonMobil*

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